Models for Type Ia Supernovae and Cosmology

(P. Hoeflich/ U. Texas at Austin)

I) Introduction

II) Explosions, light curves and spectra
- **a) Scenarios**
- **b) Model calculations**
- **c) General correlations**
- **d) Individual objects**

III) Application to cosmology and evolutionary effects with z

IV) Conclusions & future perspectives

Incomplete list of collaborators:
Baade (ESO); Dominguez (Grenada/Spain); Fesen et al. (Dartmouth);
Khokhlov etl al. (NRL/Washington); Nomoto et al. (Tokyo/Japan);
Spyromillo (ESO); Stein (Jerusalem/Israel); Straniero et al. (Rome/Italy);
Tornambee et al. (Teramo); Thielemann et al. (Basel/Switzerland);
Wang (LBL/Berkely), Howell, Marion, Wheeler (Austin); ...

MODELS FOR SUPERNOVA EXPLOSIONS

Questions to be addressed

- What is the nature of the supernovae ?

- We understand the observed correlation?
  (e.g. brightness decline relation for SNIa)

- Are normal bright and subluminous SNeIa the same kind of beast?

- Can we determine Ho independently from the distance ladder ?

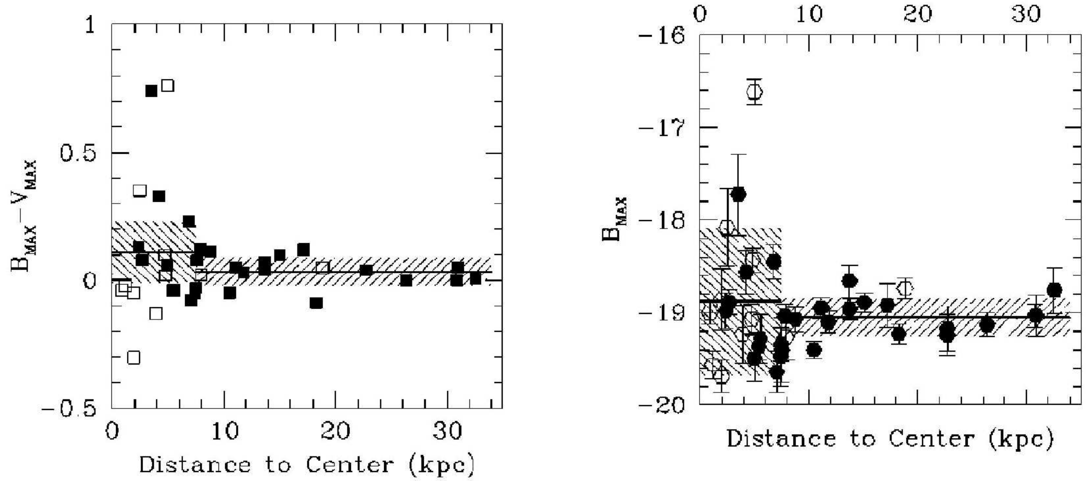
- What systematic effects do we expect and how do they show up in the observable quantities ?

- Can we find new relations which improve the accuracy?

- . . .

Evidence for Evolution (Wang, Hoeflich & Wheeler, 1998, ApJ 483, L29)

Brightness and color as a function of distance in the hostgalaxy



- Larger dispersion in B central regions
- Bluer SNe Ia in central regions

$\Rightarrow$ Intrinsic variation and not reddening

This may/can be corrected by the $M_V(dM15)$ relation
(Schmidt et al. 1998, ApJ 507, 46)

II. Cooking of a Supernova

A) Stellar evolution of a low mass star (M< 7Mo, 1E9 years) + mass-loss

=> initial structure of the WD

Method: Spherical stellar evolution code (Chieffi, Limongi & Straniero 1998, ApJ 502, 737)

B) **Quasi-static evolution of the progenitor (1E6...8 yrs) + accretion**

=> initial structure of the WD at the time of the explosion (SS-X-ray sources)

Method: Spherical accretion code (Hoeflich et al. 2000, 528, 590)

C) **The thermonuclear runaway (few hours)**

=> preconditioning of the explosive phase

Method: B) or 2D-hydro code (Hoeflich & Stein, 2001, ApJ in press /see also Vulcan)

D) **Hydrodynamical phase of explosion (1 to 60 sec)**

=> nucleosynthesis + release of explosion energy

Methods: Spherical rad. hydro including nuclear network (Hoeflich et al. 2000, ApJ 528, 589 +refs.)
+ 3-D hydro for deflagration (Khokhlov 1998, J. Comp. Phys. 143, 519)

E) Light curve (month to years) => time evolution of the expanding envelope

Methods: D) + NLTE/LTE occupation numbers (see D)

F) Detailed spectra (snapshots in time):

Methods: Spherical + 3D rad.transport + NLTE (Hoeflich 1995, ApJ 443, 89 + hab.thesis + refs.)

Explosions, LCs and Spectra

Free Parameters for

I) Explosion of M(Ch)-WD

- **Central density of the WD** (dependents on accretion rate)
- **Chemical profile of the WD** (from stellar evolution)
- **Description of the burning front** (e.g. Deflagration, DD-transition)

II) Merging WDs

- **Mass of extended envelope for mergers**

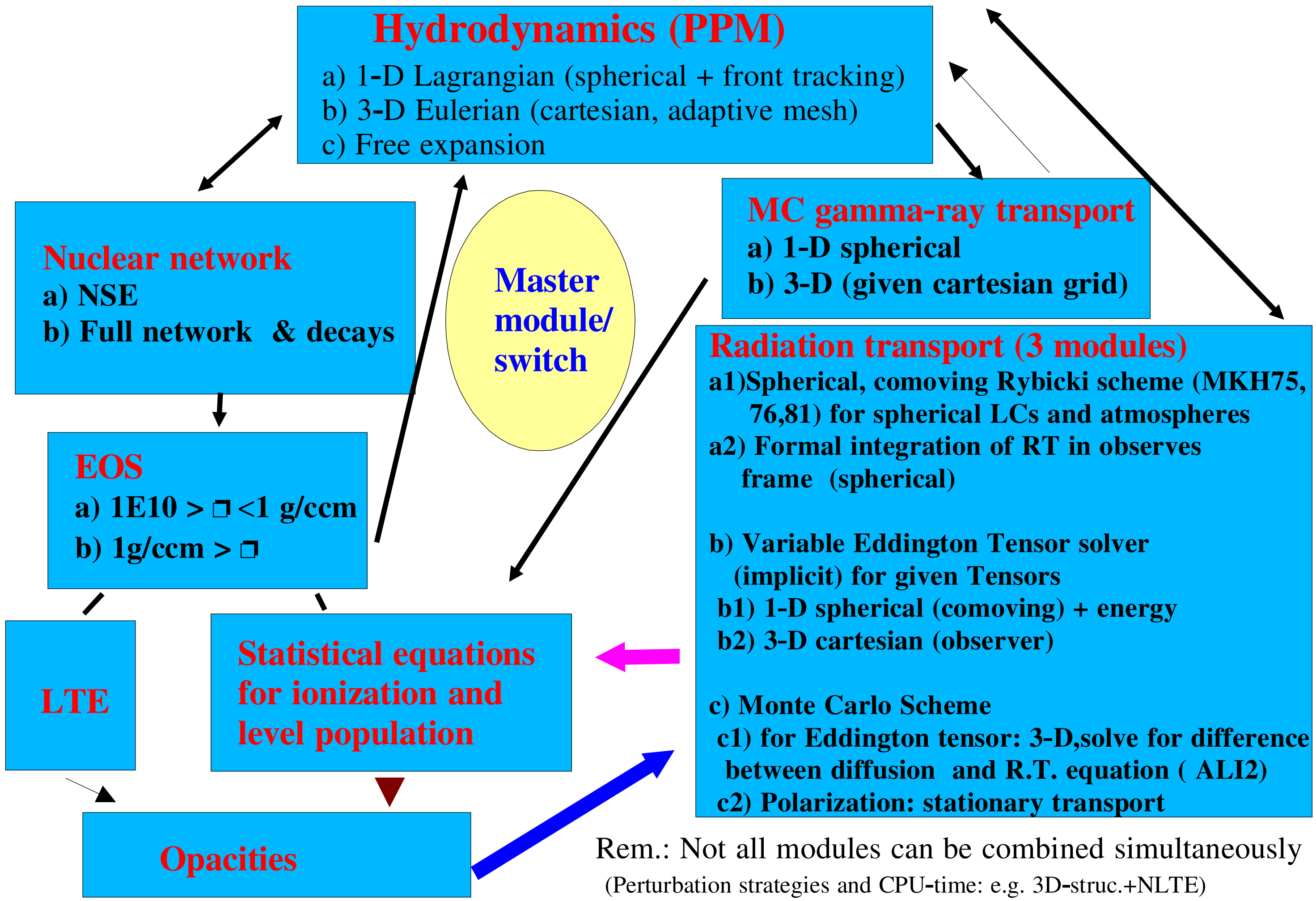
III) He-triggered explosions of sub-Chandrasekhar WDs

- **Total mass of He** (depends mainly on accretion history)

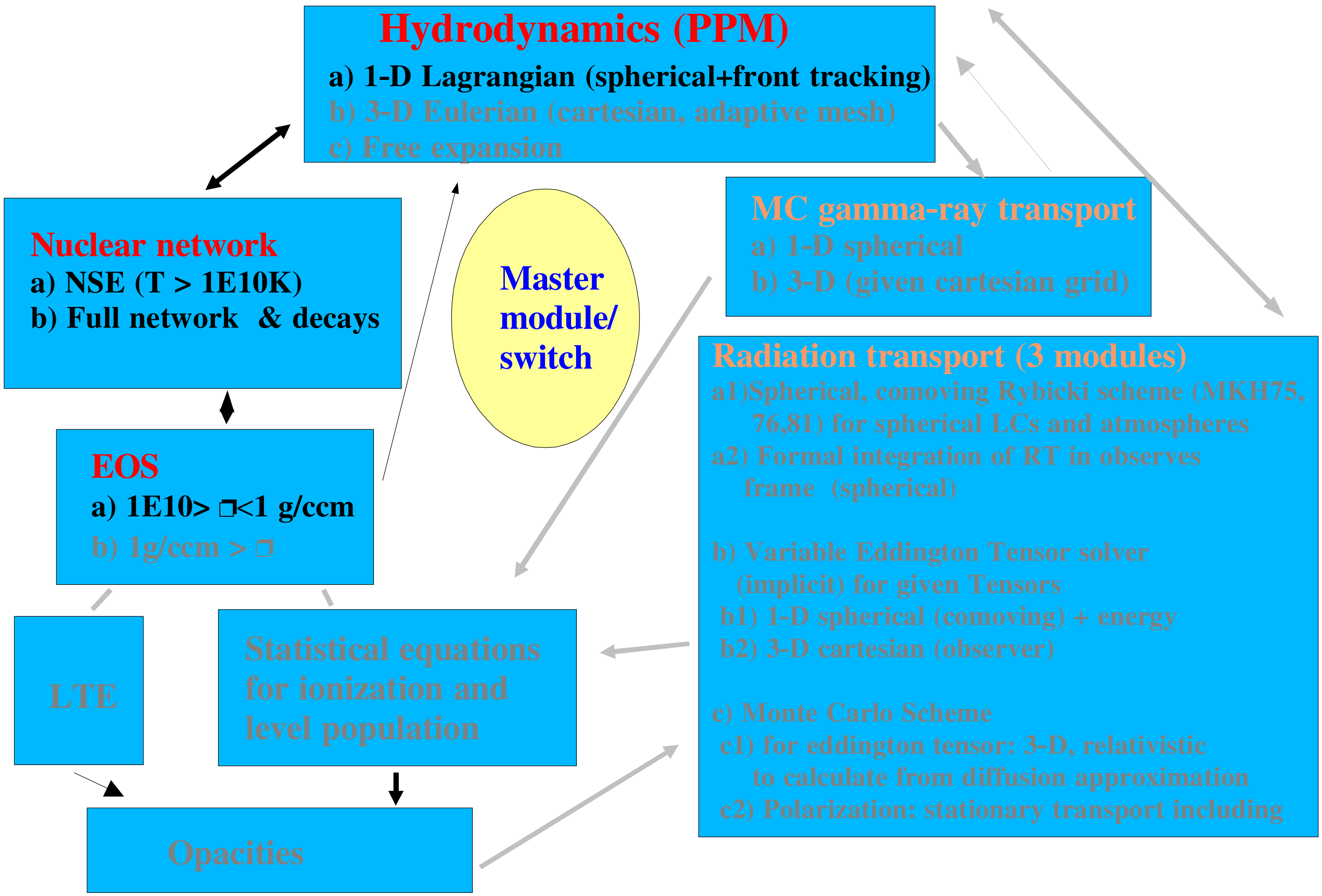
=> Observables

a) Monochromatic light curves
b) Spectra including their evolution with time
c) Polarization and directional dependence of luminosity

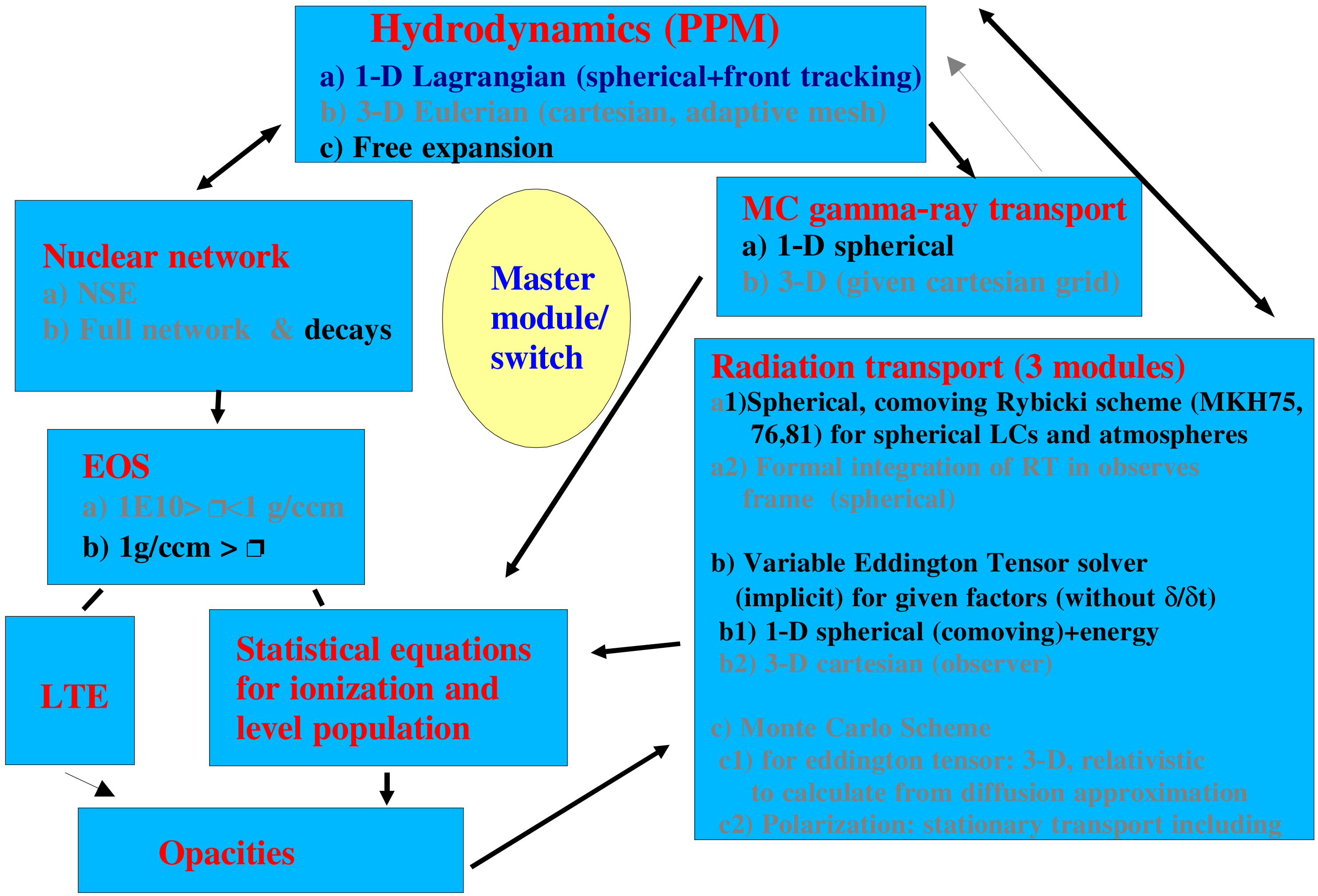
Physical Methods and Numerical Code/Modules



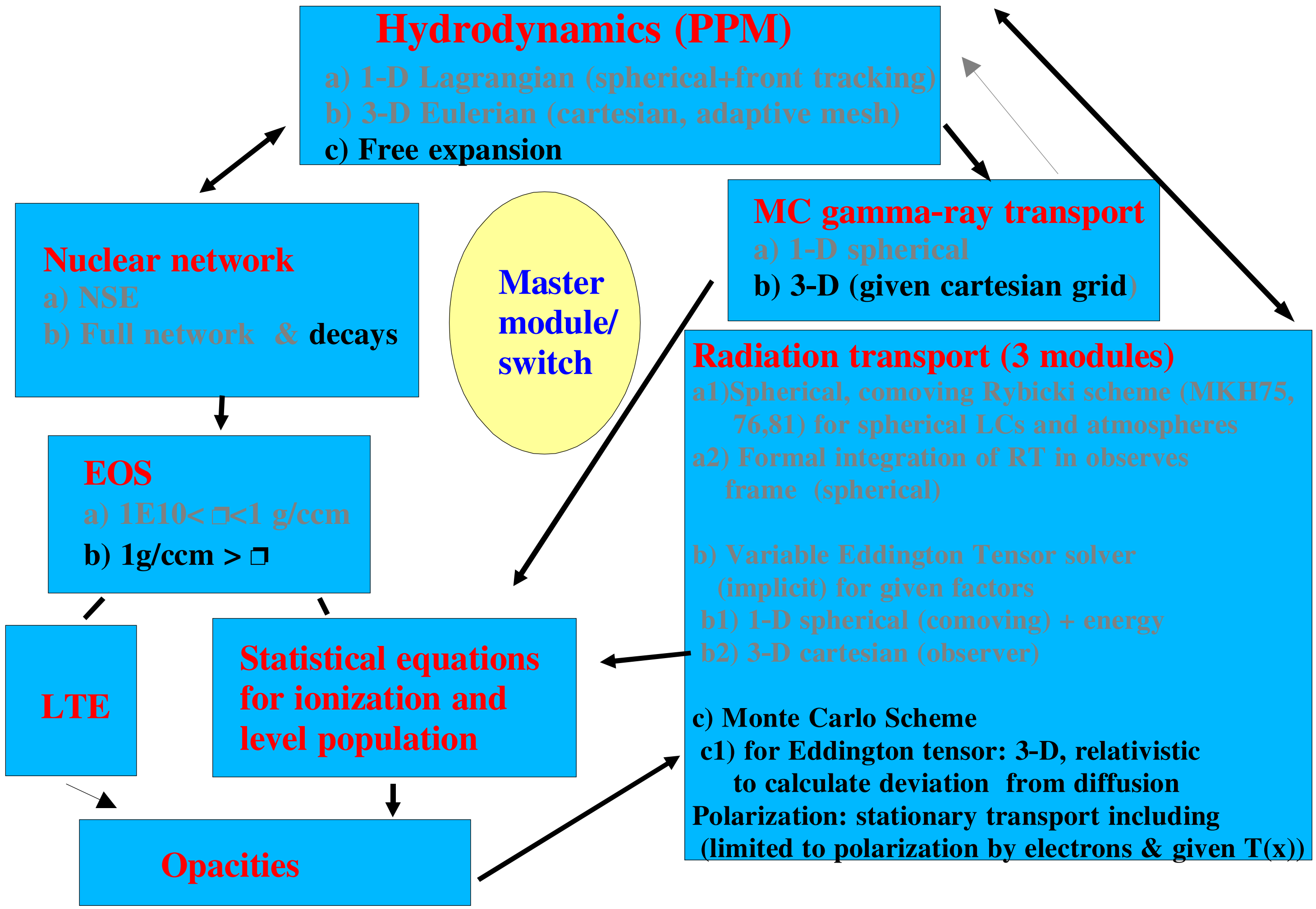
Example: Thermonuclear Explosions



Example:Numerical Environment for LCs & Spectra



Example:Numerical Environment for Polarization Spectra



Example: statistical model for subluminous SneIa

Detailed atomic models constructed from Kurucz (1993):

Ion	Levels	b-b for rate eq.	for radiation transport
CI	27	123	242
OI	43	129	506
MgII	20	60	153
Si II	35	212	506
Ca II	41	195	742
Ti II	62	75	592
Fe II	137	3120	7293
Co II	84	1355	5396
Ni II	71	865	3064
SUM	**520**	**6134**	**18650**

- Adjoining ionization stages are 3 to 5 levels

- about 1E6 additional lines with LTE-population and calibrated thermalization

- bf- and ff-cross sections from opacity project

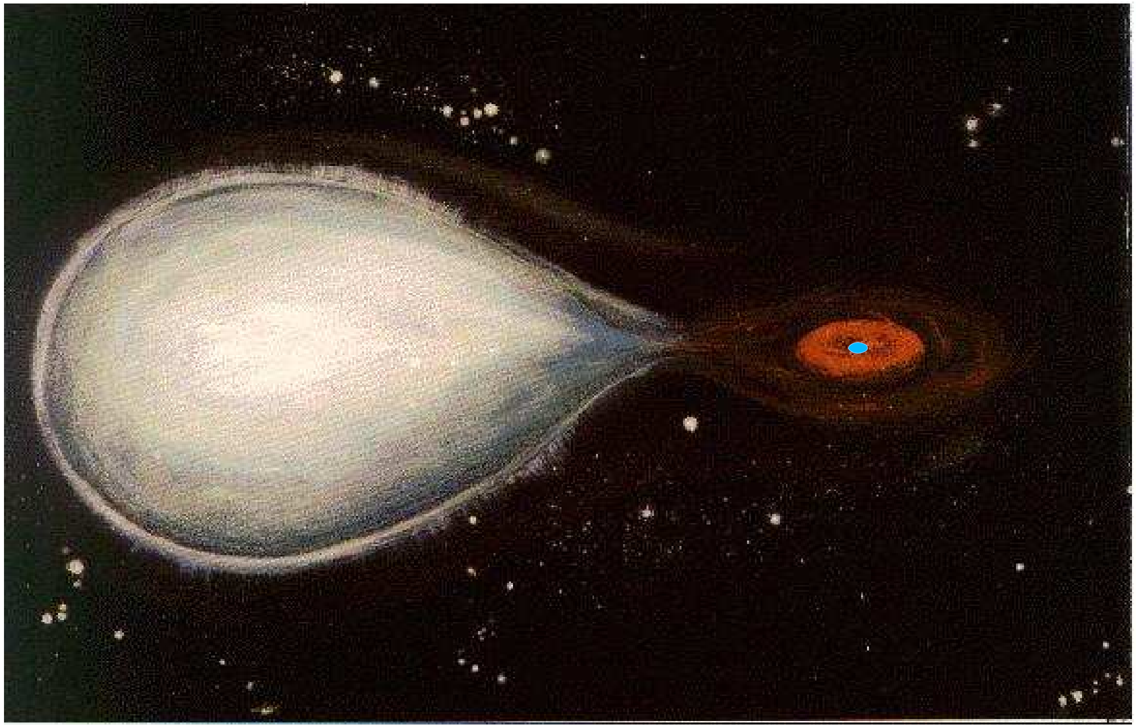
- for LC and aspherical spectra, the multiplets have been 'merged'

- Discretisation:

Spherical atmospheres: 95 spatial points, 2 to 3E4 frequencies
Aspherical " : 69/69/(69) " " , 1-3000 frequency groups (narrow line limit)
LC and gamma's : 911 " " , about 3000-5000 " " (")

I) Scenarios

1) Progenitors: Accreting White Dwarfs

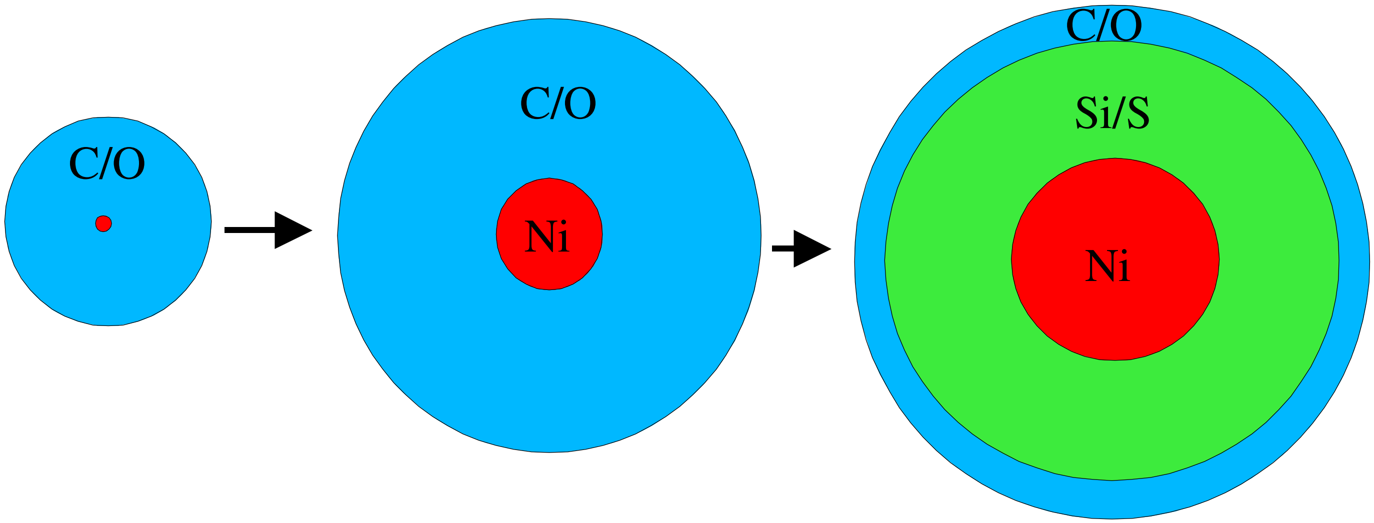


Start: WD of 0.6 to 1.2 Mo
Evolution: Accretion of H, He or C/O rich material
Explosion: Ignition when nuclear time scales are shorter than hydrodyn.

2) Progenitors: Merging White Dwarfs

Explosion of a White Dwarfs (Defl., Delayed Det. & Merger)

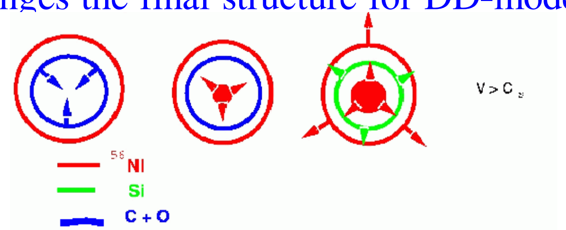
Initial WD | **Deflagration phase(2...3sec)** preexpansion of the WD | **Detonation phase (0.2...0.3 sec)** hardly any time for further expansion



Deflagration: Energy transport by heat conduction over the front, v <<v(sound)=> ignition of unburned fuel (C/O)
Detonation: ignition of unburned fuel by compression, v = v(sound)

Rem1: Pre-expansion depends on the amount of burning. The rate of burning hardly changes the final structure for DD-models (Dominguez et al. ApJ 528, 590)

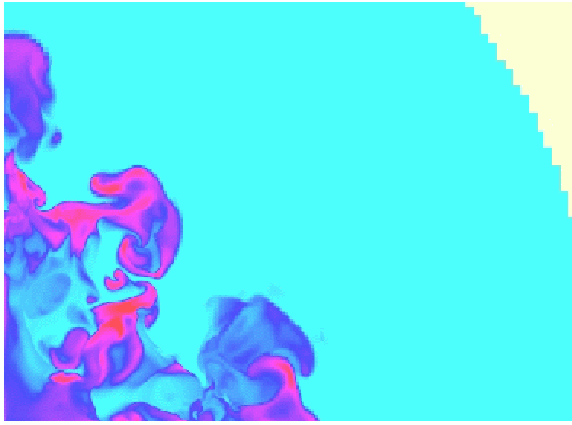
Rem.2: HeDs (sub-MCh)

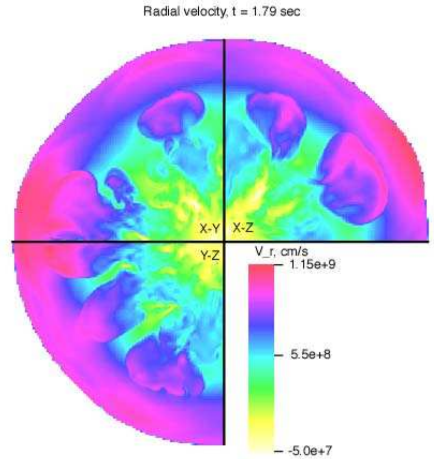


- disagree with LCs and spectra
(Nugent et al. 96, Hoeflich et al. 96)

Propagation of the Deflagration Front (from Khokhlov, 2001, ApJ, in press)

Burning of a WD at 2.5 sec

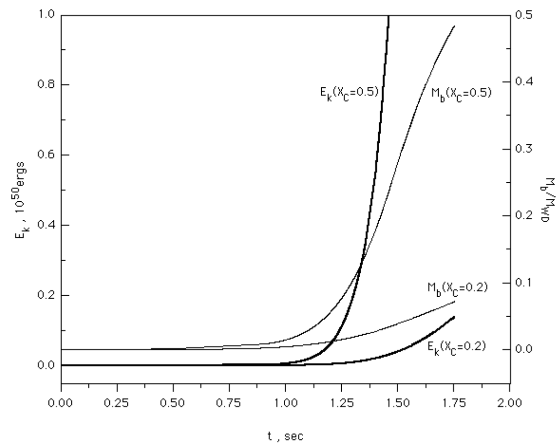




- Blobs mix into layers corresponding to about 8000 km/sec in the hom. ph.

Some Remarks:

- pre-expansion depends on the amount of burning (-> does not depend on details of burning)
- expansion becomes spherical
- but inhomogenities in the abundances
- size and amount of burning depends on C/O



Transition from Deflagration to Detonation

Possible mechanism:

1) Zeldovich mechanism: Mixing from burned and unburned material
(Khokhlov et al. 1997, Niemeyer et al. 1997)

- Problem: works only for low fluctuations in the background

2) Crossing shock waves (e.g. Livne 1997)

- Problem: Is the 'noise' sufficient or do we need some reflection
at boundaries?

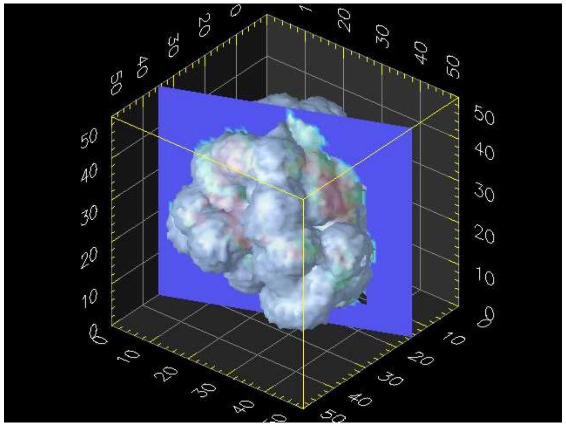
3) Shear flows at low densities (e.g. Livne/Aspen workshop 1998)

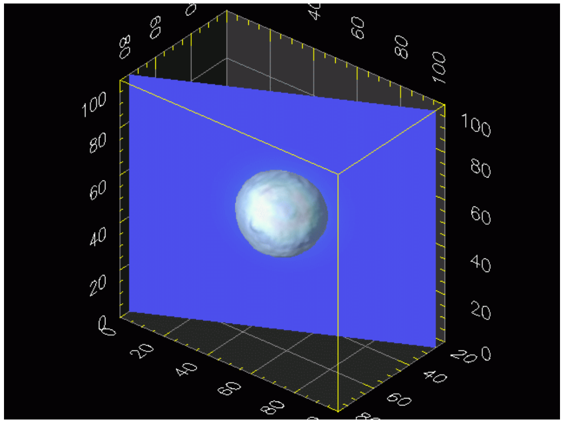
- Problem: Does it work?

3-D Structure for a deflagration model

WD: Mch, rho(c)=2E9 g/ccm

Day 01 **Day 21**

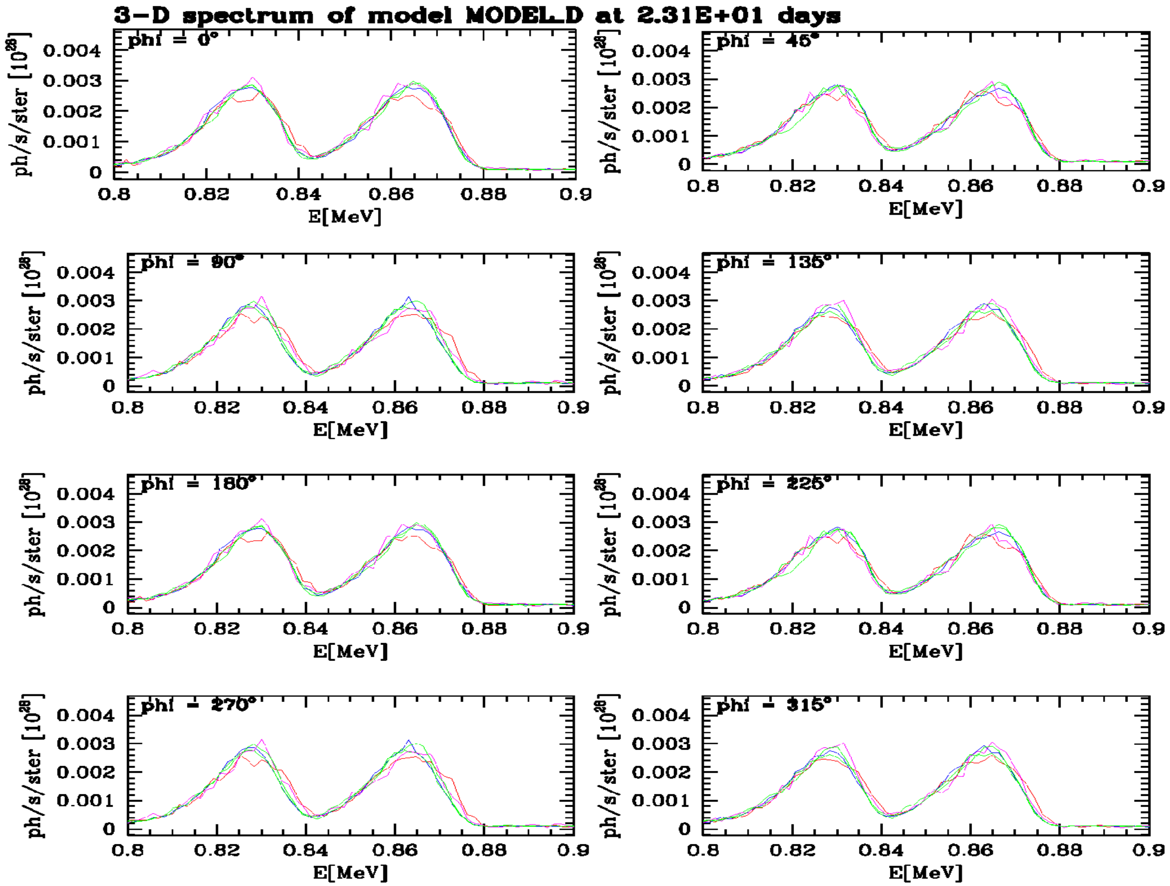




Contour: 2% of maximum Ni deposition

- Energy deposition is highly aspherical early on but spherical later on

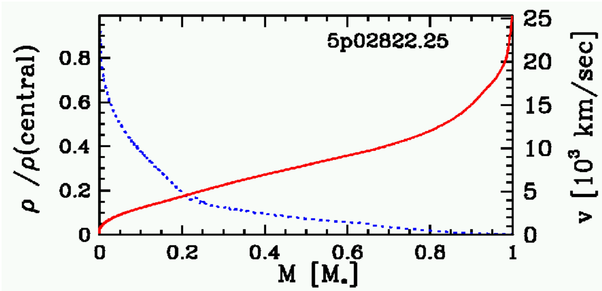
3-D spectrum for a deflagration model (Example at day 23)

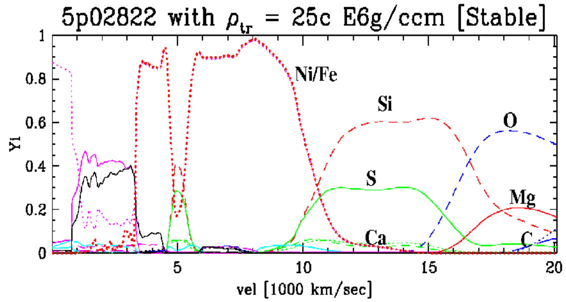


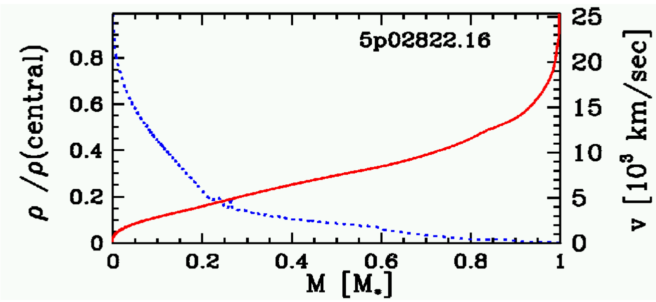
Remark: Likely, a DDT would produce an almost spherical Ni distribution but ...

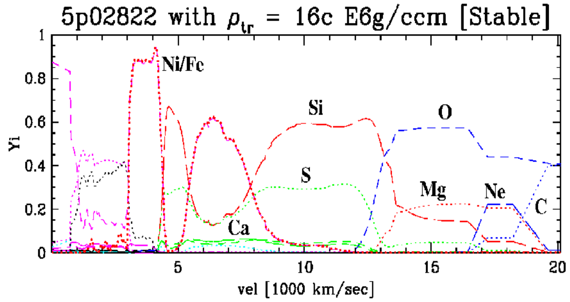
Delayed detonation models for various transition densities rho(tr)

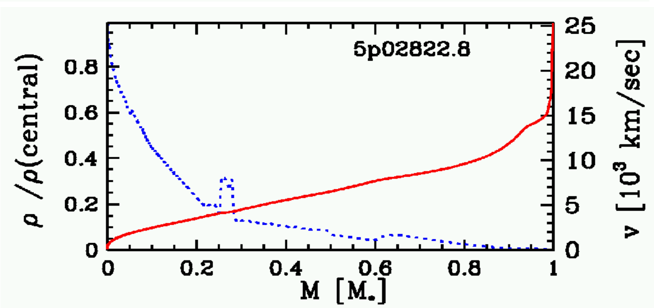
[M(MS)= 3 Mo; Z = 1.E-3 solar; rho(c)= 2E9 g/ccm with rho(tr)=8, 10,12,14,16,18,20,23,25,27 g/ccm]

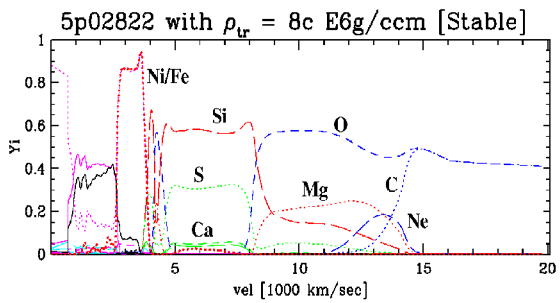












Rem.: similar explosion energyies but very different chemical structures (Fact. 6 in M(Ni)) !!!

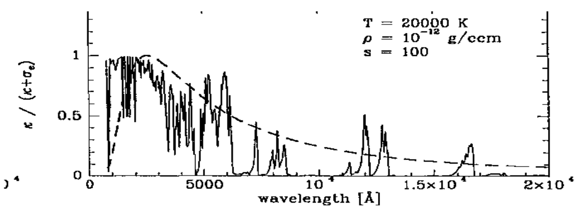
Rem2.: Minimum Ni mass is given by burning during the deflagration phase

III) Correlations: The Brightness Decline Relation

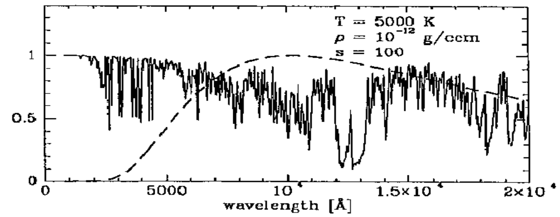
Remarks on Opacities & Emissivities (Hoeflich et al. 1992, AA 268, 510)

Frequency dependence of $\chi(\nu, T, \rho, dv/dr)$ between 1000 -20000 Å

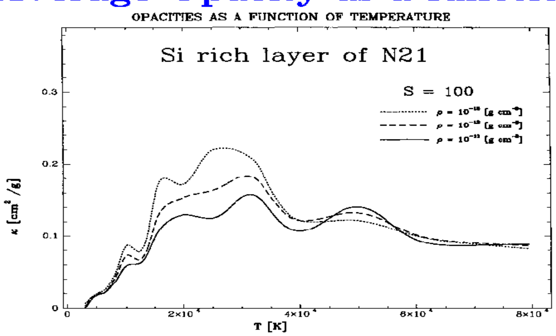
T = 20000 K



T=5000 K



Average Opacity as a function of Temperature

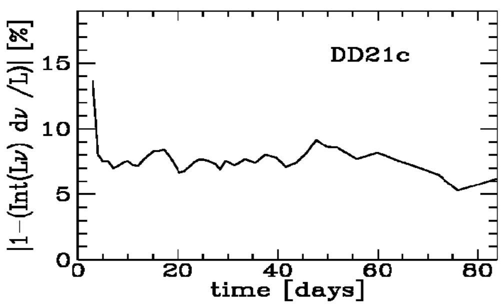


- Opacity drops fast for T < 10000 K

Reasons:

- Emissivity shifts into the optical
- line blanketing is less in optical vs. UV
- thermalization is higher

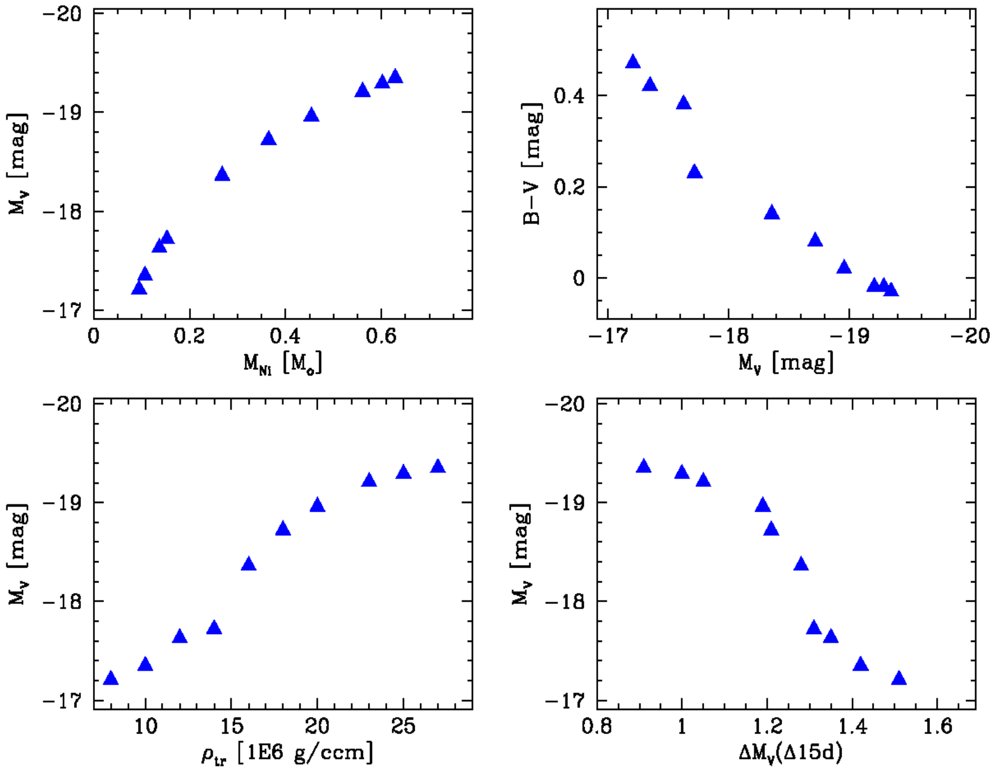
Consistency check: $L(\bar{\kappa}) vs. L(\kappa_\nu)$



See brightness decline relation

Correlations for DD-Models

Example: rho(c)=2.E9g/ccm; M(MS)=5Mo



Basic variables

1) DDT transiton density

2) Structure of progenitor
(Metallicity & M(MS)

3) central density of WD
(accretion rate)

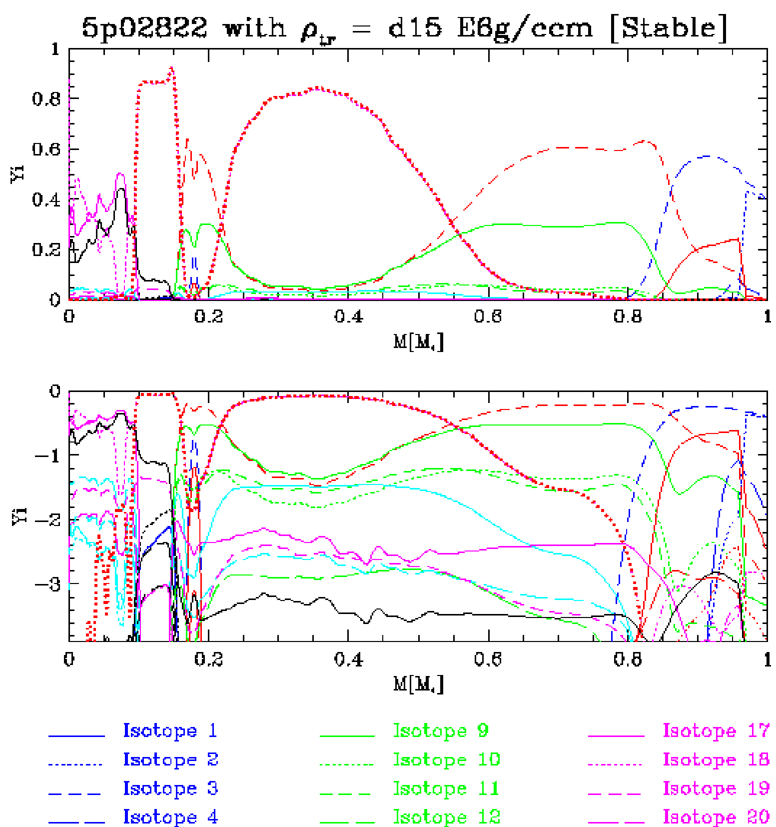
- rho(tr) determines M(Ni) (structure of WD and rho(c) produce a spread of 0.4mag)

Delayed detonation models for various central densities

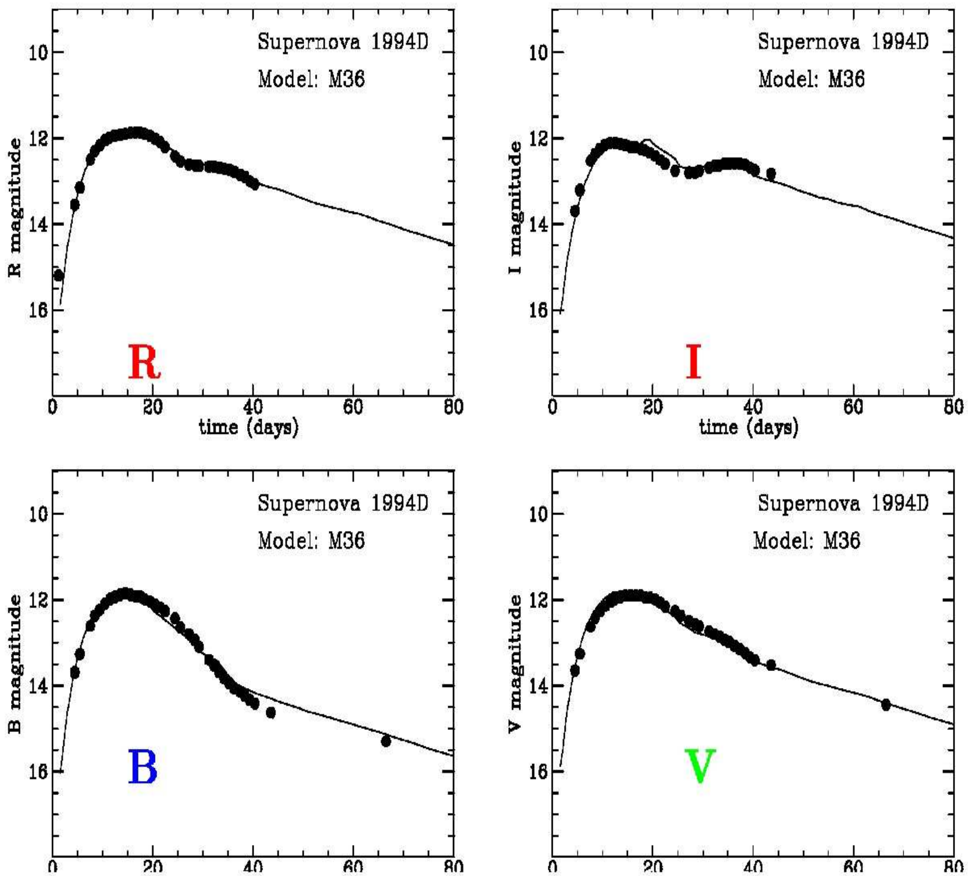
[M(MS)= 3 Mo; Z = 1.E-3 solar; rho(tr)=2.3E7g/ccm]

Remark: The central density depends on the accretion rate on the WD

- rho(c) determines the size of region with production of neutron-rich isotopes
- M(Ni) production changes by 20 % between rho(c) 1E9 to 6E9 g/ccm



IV) Individual Objects: SN94D vs. DD-models



LCs up to day 80

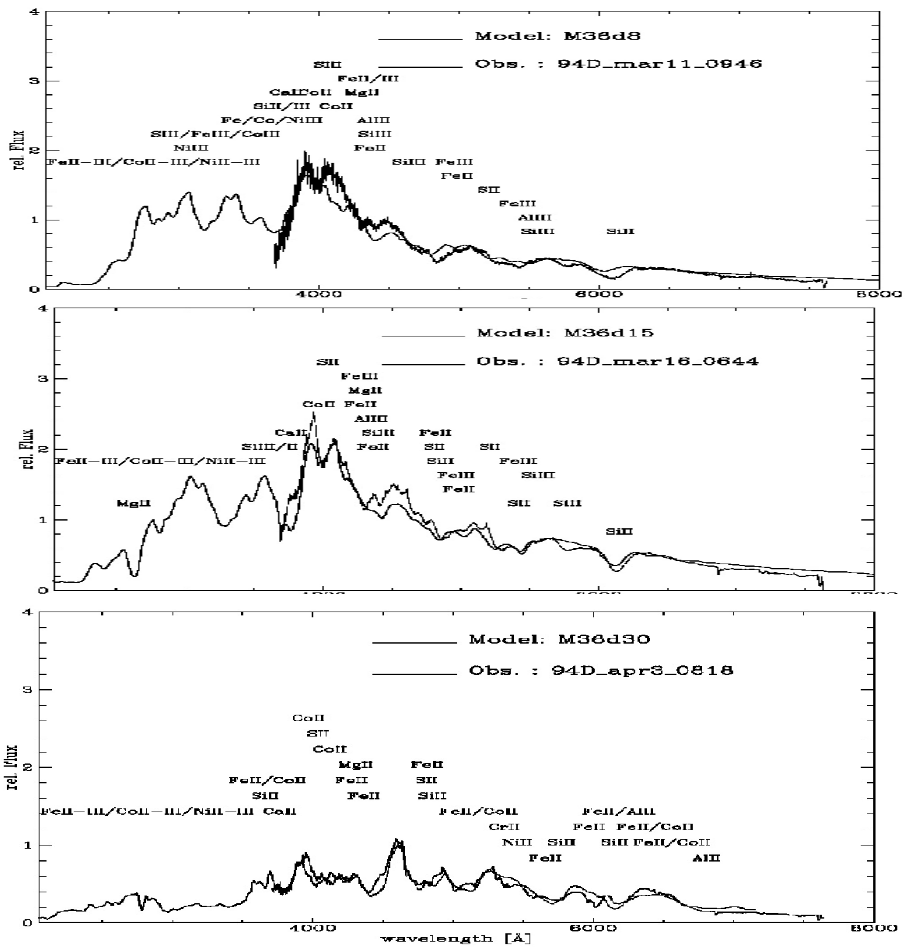
C/O WD with

rho(c)=2.E9g/ccm

rho(tr)=2.4E7 g/ccm

Spectra between 3000 and 8000 A: SN94D vs. M36

C/O WD; rho(c)=2.E9g/ccm; rho(tr)=2.4E7 g/ccm



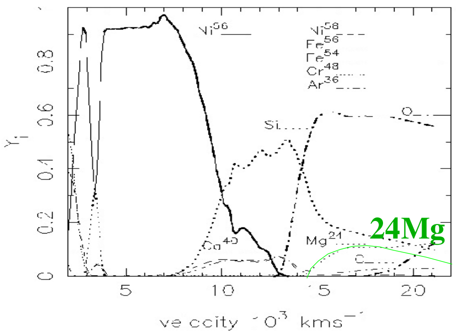
- 8 days after explosion
  = 1 week before maximum
  - spectrum is dominated by intermediate mass elements (S,Si) + iron group elements

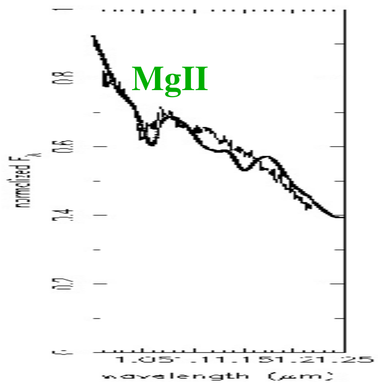
- 16 days after the explosion
  = maximum light
  - spectrum is dominated by Si, S, Ca + iron group elements (formed in transition layer between Si and Ni/Co/Fe

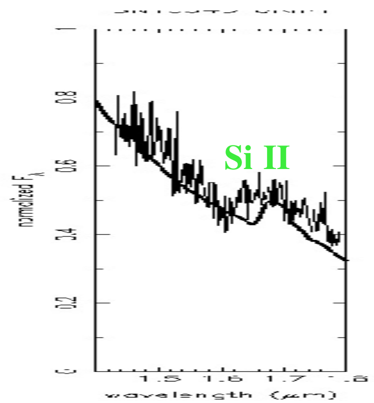
- 30 days after explosion
  = 2 weeks after maximum
  - spectrum is formed in inner Ni/Co/Fe core

IR-Spectra at Day -3 in Comparison with SN1994D at Day -7

Spectra between 1.05-1.25 & 1.4-1.8 A







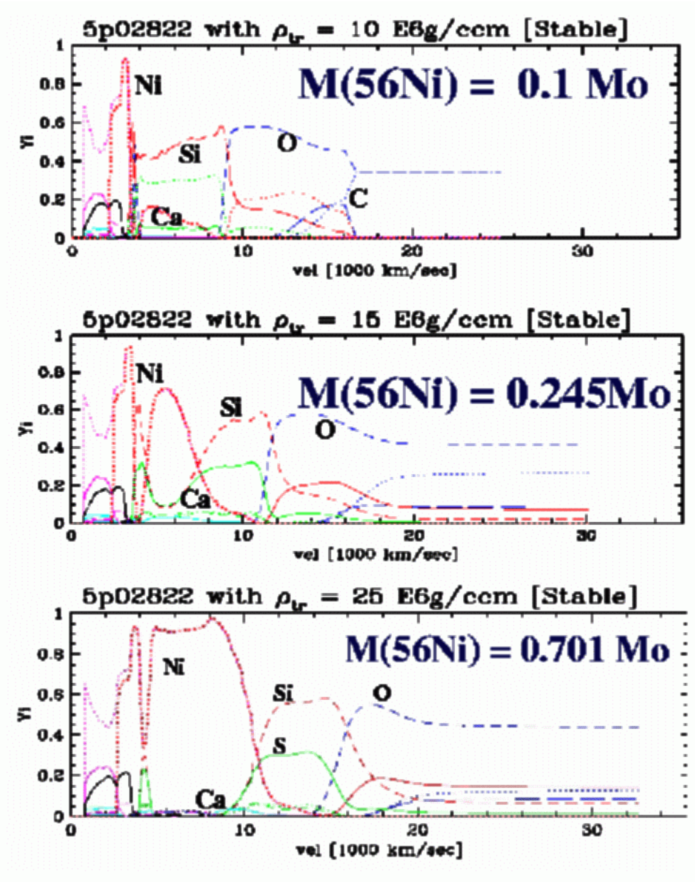
Observation of SN1994D by P.Meikle

- Explosive carbon burning up to the outer 1E-2 Mo

- Si lines at high velocities are not due to mixing !!!

Chemical Structures for Delayed-Detonation Models

C/O-WD; rho(c)=2.E9 g/ccm; M(MS)=5Mo



- start with slow deflagration front
  RT unstable -> acceleration

- Prompt transition to detonation

- Produces both normal bright
  and subluminous SN

- Avoids problem electron capture at center.
  (with new rates + adaptive mesh-hydro.
  => rho(c) may be up to 3.5E9g/ccm)

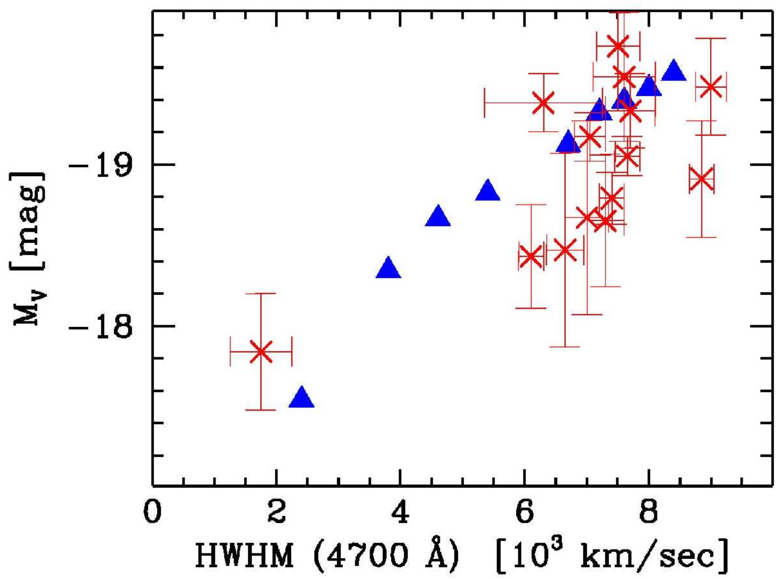
(Fits well for a lot of S NeIa)

Mean Velocity of Ni by Late Time Spectra

(Mazzali et al. 1998, ApJ 499, L49)

IDEA: Use the line width of the 4700 A FeII-feature during late phases to determine the mean distribition of Ni

List of SN: 81B, 86G, 89B, 90N, 91M, 91T, 91bg 92A, 93L, 94D, 94ae, 95D. 96X



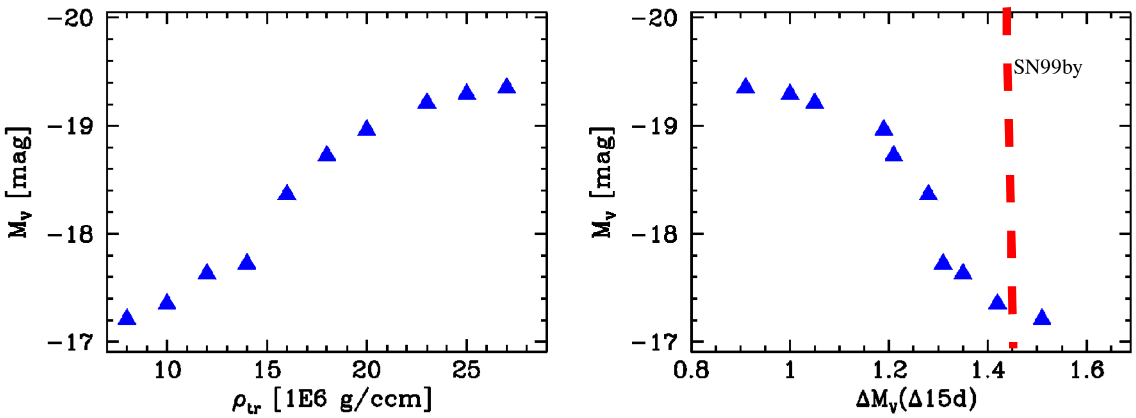
- direct measurment of Ni-distribution

- Ni is indeed in the central region for both normal and subluminous SN

Model assumption:
Optically thin

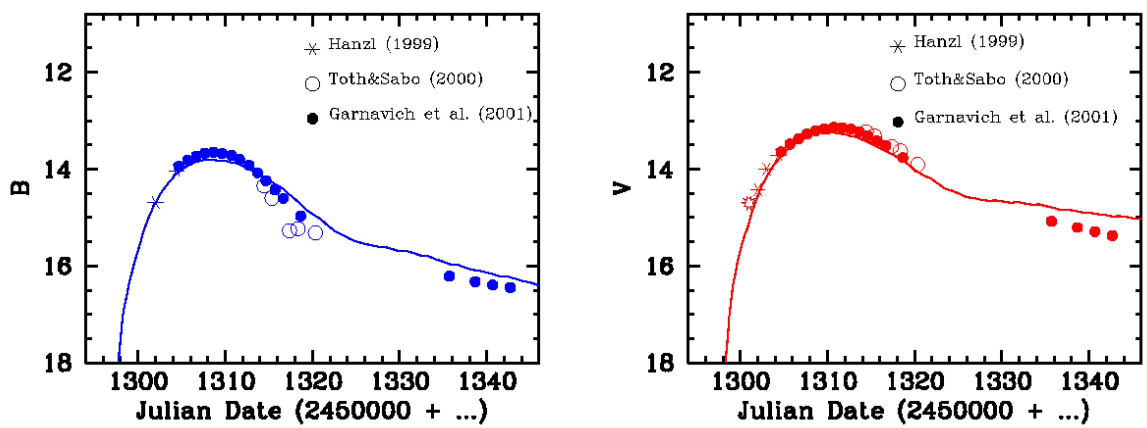
Analysis of SN1999BY (fast track)

Select model based on optical LC and spectra: here, the brightness decline ratio



- M(V) = F(❐(tr))
- SN1999BY is at the lower end

Comparision between observed and theoretical LC



Discrepancy in B and V

- **0.05 mag (tmax)**
- **0.4 mag (tmax+30d)**

consistency error

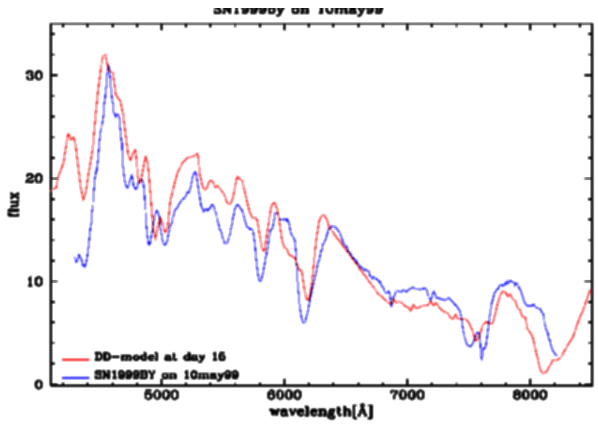
between NLTE and LC calculation

- **0.07 mag (tmax)**
- **0.2 mag (tmax+30d)**

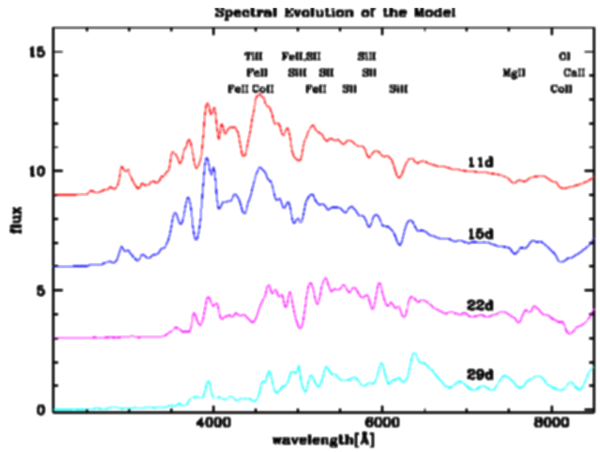
Remark: Compare old LTE + calibration (HKW95) for subluminous SN error(tmax) in (B-V)=0.2 m

IR-Analysis of SN1999BY (as followed from explosion without tuning)

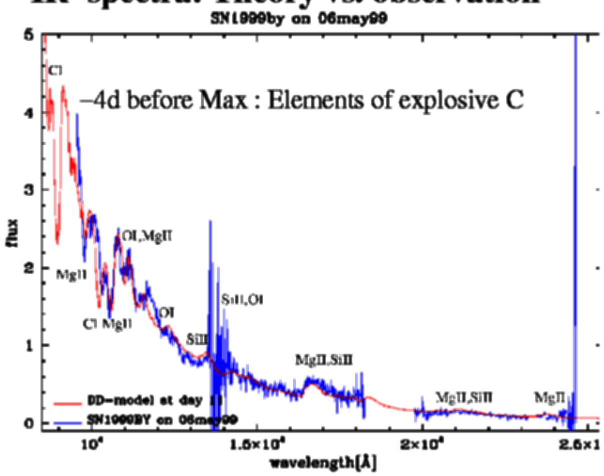
Optical spectrum at maximum light

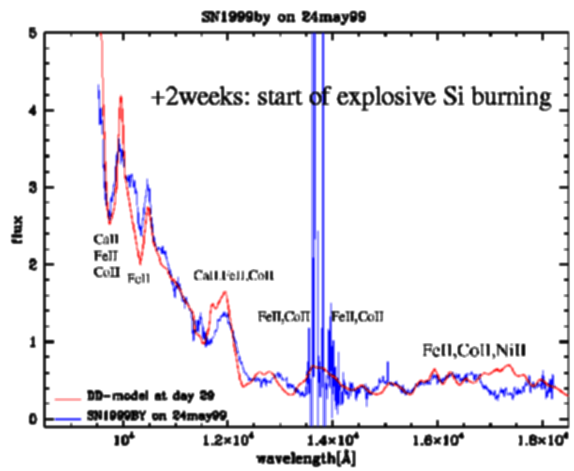


Evolution of theoretical spectra



IR–spectra: Theory vs. observation



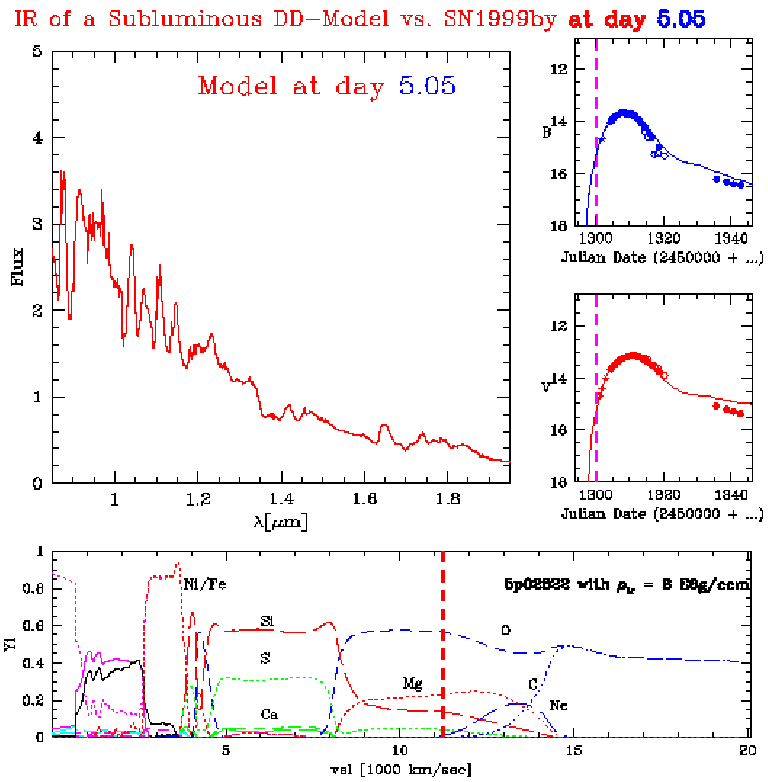


Ni is located in the center and little or no mixing occured. Is this the reason for the subluminosity?

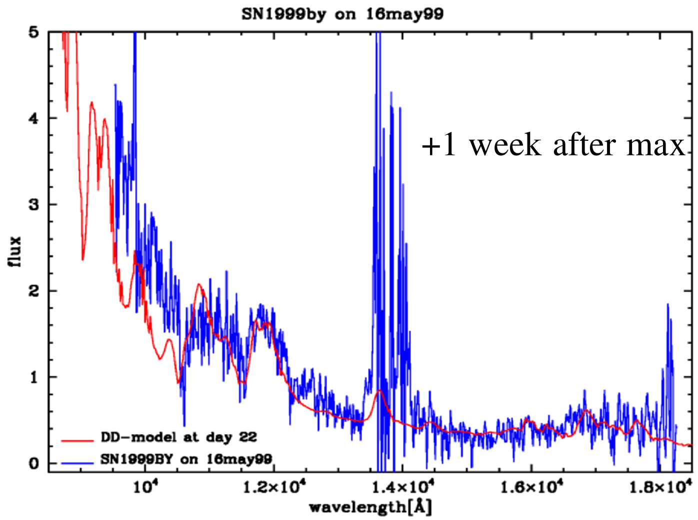
–4d before Max : Elements of explosive C

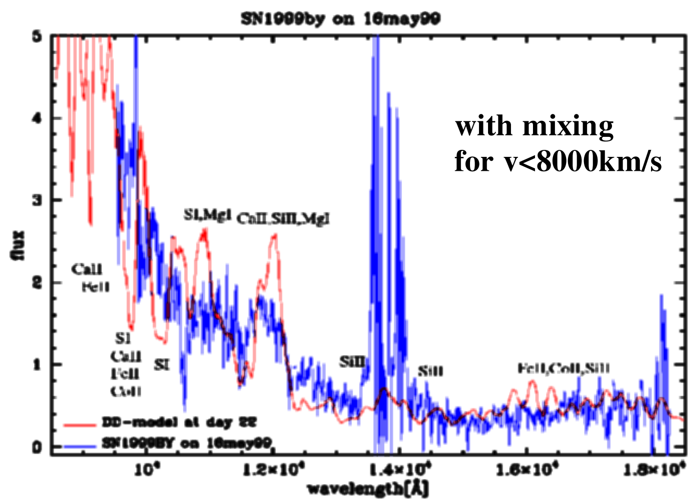
+2weeks: start of explosive Si burning

IR-Analysis of SN1999BY (as followed from explosion without tuning)



Do we have a smoldering phase or a deflagration phase?





Mixing, predicted from 3-D deflagration model does not occur

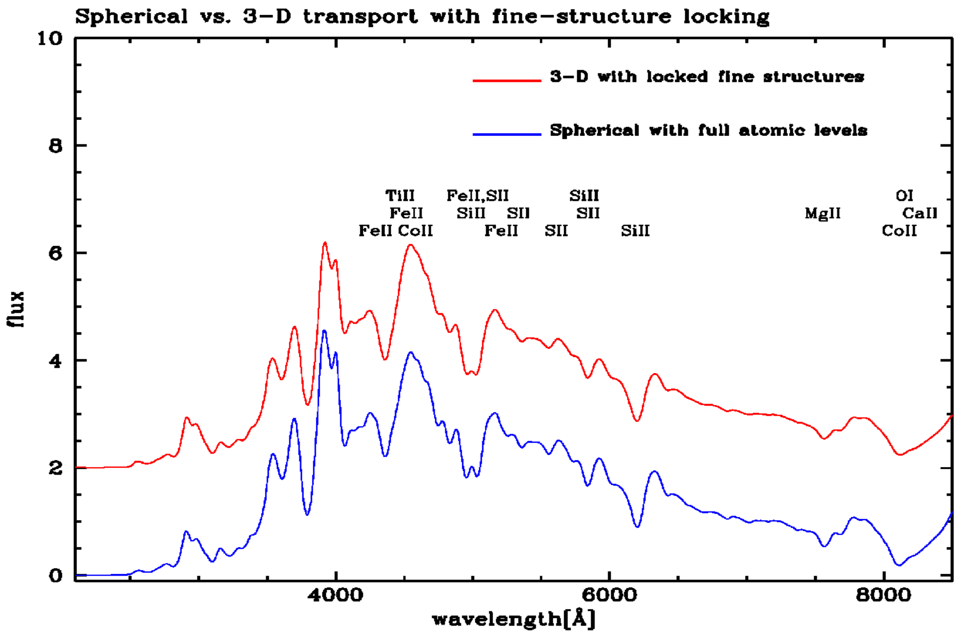
- No deflagration phase ?

- Smoldering phase ?

- Influence of rotation ?

In any case, importance of preconditioning of the WD is obvious.

Influence of Level-Locking



- qualitatively ok but ...
  some discrepancies in particular below 5000 A due to
  a) locking of levels
  b) frequency resolution
  c) for net-rates below 1E-3, deviations from diffusion is set to zero

Definition of Polarization

Electromagnetic wave : $\psi(z,t) = Ee^{i(kz-\omega t)}$

$\underline{E} = (E_x, E_y)$

Intensity is defined as the time average over many waves

$I = I_0 + I_{90} = \overline{E_x\ E_x^* + E_y\ E_y^*} = \overline{E_x^2 + E_y^2}$

Degree of polarization P

$P = (I_0 - I_{90})/(I_0 + I_{90})$

with position angle χ

Alternative Definition: Stoke's parameters

$Q = I_0 - I_{90}$

$U = I_{45} - I_{-45}$

$V = 0$ for linear polarization

Rem.: $tan\ 2\chi = U/Q$ and $P = \sqrt{Q^2 + U^2}$

Polarization in SN Atmospheres by Thomson Scattering

Example: oblate and prolate ellipsoides with and axis ratio of 2 seen from the equatorial plane:

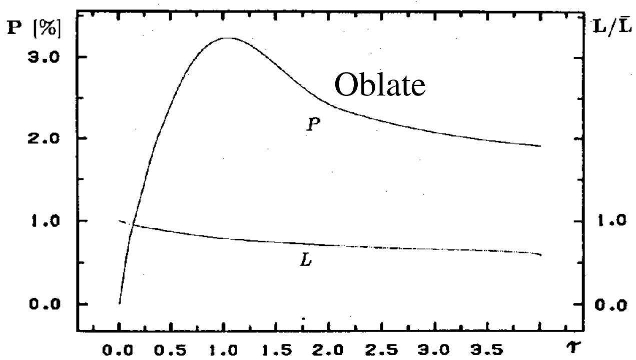


Fig. 1. Linear polarization (P) and the normalized flux (L) as a function of the maximum optical depth τ for an oblate ellipsoid [$N(r) \propto r^{-2}$; $\varepsilon=0.01$; $E=0.5$; spherical inner boundary, $i=90°$]

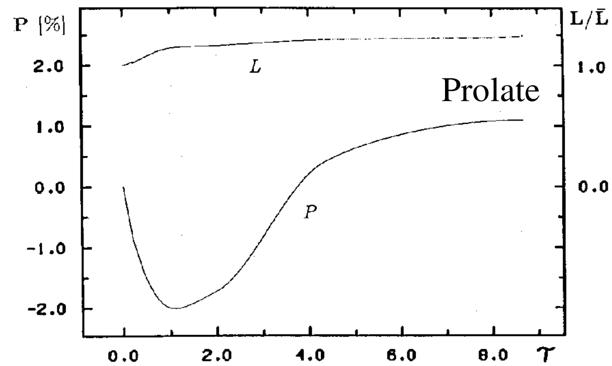
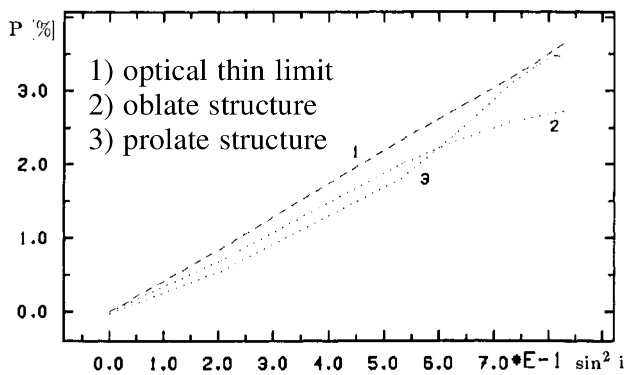
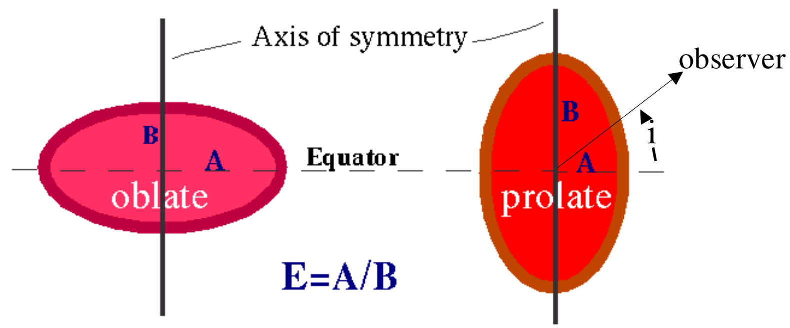


Fig. 5. Linear polarization (P) and the normalized flux (L) as a function of τ_{max} for a prolate ellipsoid [$N(r) \propto r^{-2}$; $\varepsilon=0.01$; $E=0.5$; spherical inner boundary; $i=90°$]

Dependence of P from the inclination



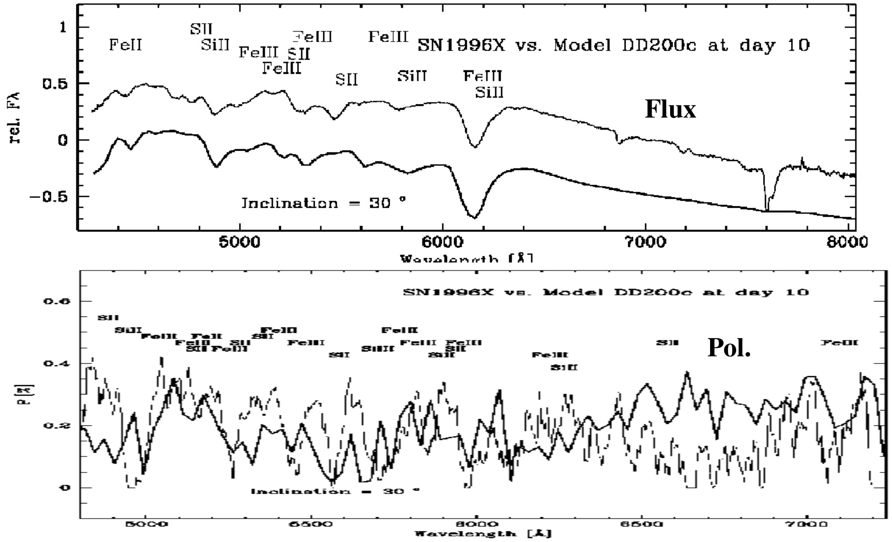
P depends on the inclination of the observer !



Polarization in Type Ia Supernovae

SN1996X around maximum light (Wang et al. 1998, ApJ 476, 27)

Comparison with a DD-model for normal bright SNIa (DD200c)



- no depolarization in Si II but in Fe II features

general pattern is ok

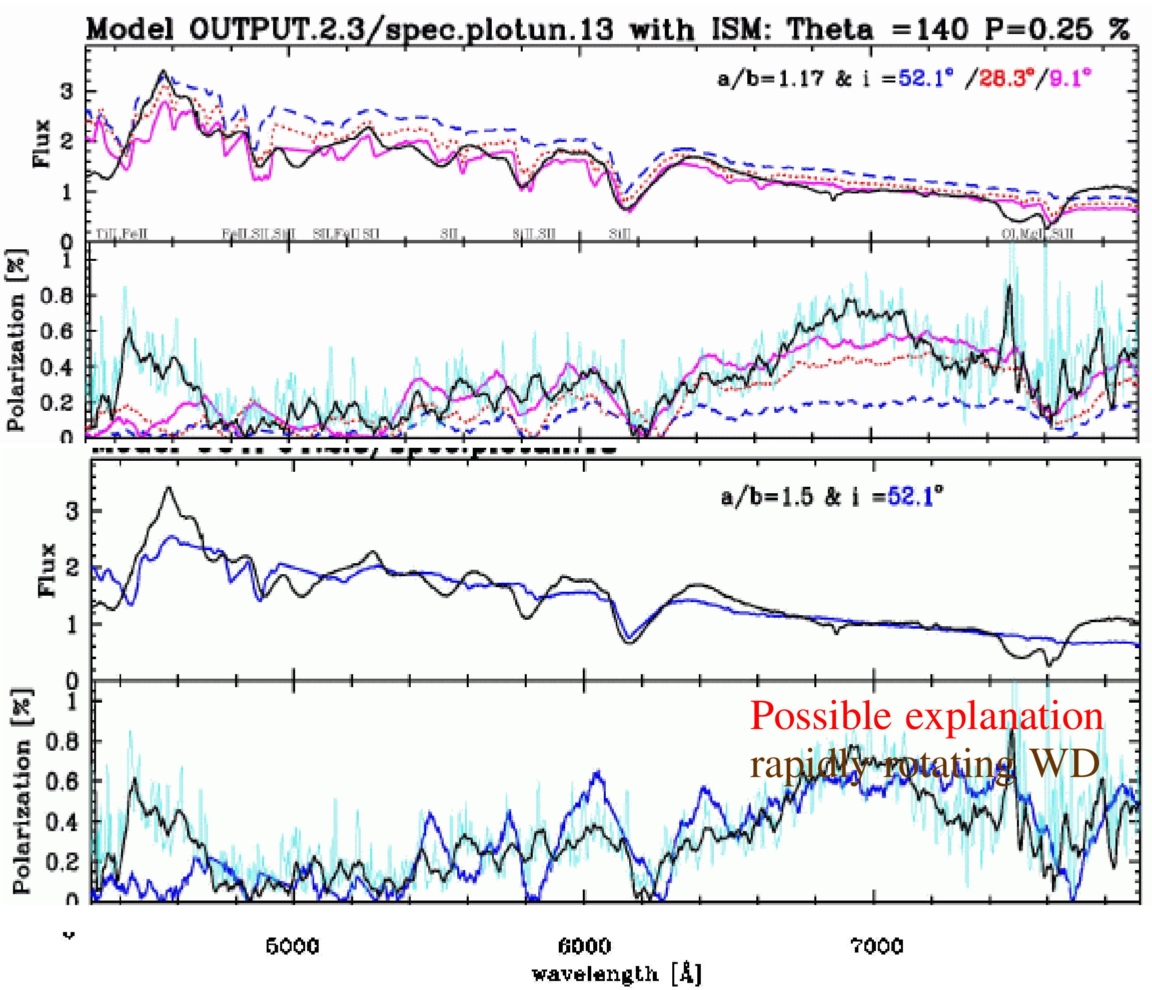
asphericity of 10 % in Ni-region may be present

The subluminous SN 1998by (PhD thesis of Andy Howell, UT)

- P(max) is about 0.5 % in the near continuum (lam>7000 A) and about half in the optical. Strong depolarization in Si II !!!
- Suggestion: Asphericity in structure of about 15 % (preliminary)

Polarization of the subluminous SN1999bu vs. prolate model

(Howell, Hoeflich, Wang, Wheeler, ApJ, in press)

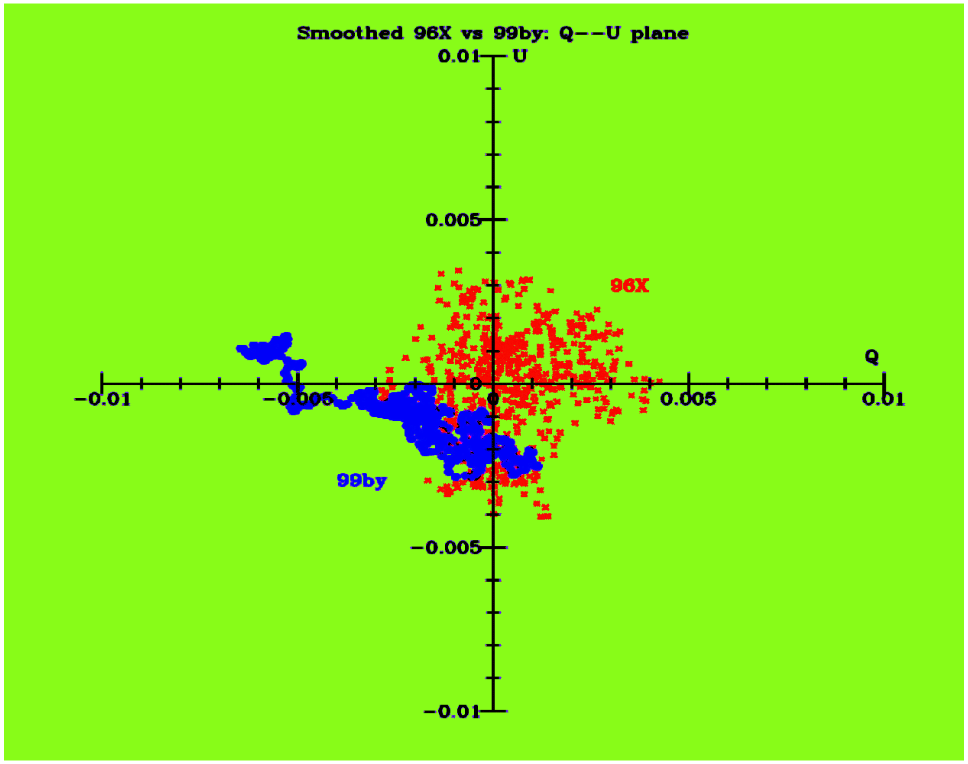


- global asymmetry
- asphericity 17 %
- seen equator on

- larger axis + higher inclination does not work

Possible explanation rapidly rotating WD

The U/Q-plane or the nature of asymmetries



=> a) random orientation in SN1996X (or noise) but also seen in SN2000el
b) axial symmetry in SN1999by

V) Cosmology: Comparison of 27 SNeIa with Models (HK96)

Supernovae	in galaxy	Type	v_z	M-m	D[Mpc]	E_{B-V}	acceptable models	
SN 1937C	IC 4182	Sm	326	28.3	4.5 ± 1	0.10	N32,W7,DET2	x
SN 1970J	NGC 7619	dE	4019	34.0	63 ± 8	0.01	DET2ENV2/4, (PDD3)	
SN 1971G	NGC 4165	Sb	1703	32.8	36 ± 9	0.04	M37, M36, W7, N32	
SN 1972E	NGC 5253	I	407	28.0	4.0 ± 0.6	0.04	M35,N21,M36 (HeD12 [2])	
SN 1972J	NGC 7634	SBO	3374	33.6	52 ± 8	0.01	W7,M36/37,N32,DET2	
SN 1973N	NGC 7495	Sc	5126	34.2	69 ± 20	0.08	N32, M36, W7, (HeD10/11)	
SN 1974G	NGC 4414	Sc	715	31.2	17.5 ± 5	0.0	N32,M36,W7,DET2 (HeD10/11)	
SN 1975N	NGC 7723	SBO	1823	32.2	28 ± 7	0.18:	PDD3/6/9/1a	
SN 1981B	NGC 4536	Sb	1647	31.4	19 ± 4	0.05	M35, N21	
SN 1983G	NGC 4753	S	1126	31.4	15 ± 4	0.29	N32, W7 (M36)	x
SN 1984A	NGC 4419	Ep	1187	31.1	16 ± 4	0.14	DET2ENV2, PDD3/6)	
SN 1986G	NGC 5128	I	530	28.1	4.2 ± 1.2	0.83	W7, N32, (M37/8)	
SN 1988U	AC 118[1]	-	91480	40.8	1440 ± 250	0.05	M36, W7, N32	
SN 1989B	NGC 3627	Sb	726	29.7	8.7 ± 3	0.45	M37, M36	x
SN 1990N	NGC 4639	Sb	971	31.5	20 ± 5	0.05	DET2ENV2/4, PDD3/1a	
SN 1990T	PGC 63925	Sa	11980	36.2	180 ± 30	0.1	M37, M38	
SN 1990Y	anonym.	E	11680	36.4	195 ± 45	0.05	W7, N32, M36/37, PDD3/6/1c	
SN 1990af	anonym.	E	14989	37.1	265 ± 85	0.05	W7, N32, M36	
SN 1991M	IC 1151	Sb	2188	33.10	41 ± 10	0.12	M35, PDD3	x
SN 1991T	NGC 4527	Sb	1727	30.4	12 ± 2	0.10	PDD3/6/1a. DET2ENV2	
SN 1991bg	NGC 4374	dE	954	31.3	18 ± 5	0.25	PDD5/1c	
SN 1992G	NGC 3294	Sc	1592	32.4	29 ± 6	0.05	M36, M35, PDD3, HeD10	
SN 1992K	ESO269-G57	SBb	2908	33.2	43^{+15}_{-8}	0.18	PDD5/1a,(M39, HeD2)	
SN 1992bc	ESO-G9	S	5960	34.6	83 ± 10	0.04	PDD6/3/1c	
SN 1992bo	ESO-G57	S	5662	34.5	79 ± 10	0.03	PDD8	
SN 1994D	NGC 4526	S0	487	31.1	16 ± 2	0.00	M36, (W7, N32)	

[1] the host galaxy is member of the cluster 118
[2] can be ruled because spectra indicate Si at higher velocities

- Delayed detonation models and, in some cases, merger scenarios (X) are consistent
- Comparison of absolute brightness of models and apparent brightness provide distances
- Multi-color fits provide the reddening A(Color) = R (color) E(B-V)

HUBBLE CONSTANT (from Hoeflich and Khokhlov 1996) **(Hubble law v = Ho r)**

based on 27 SNe~Ia: 67 +- 8 (2 σ) km/sec/Mpc

For Comparison:

Miller and Branch 1995: 51 km/sec/Mpc

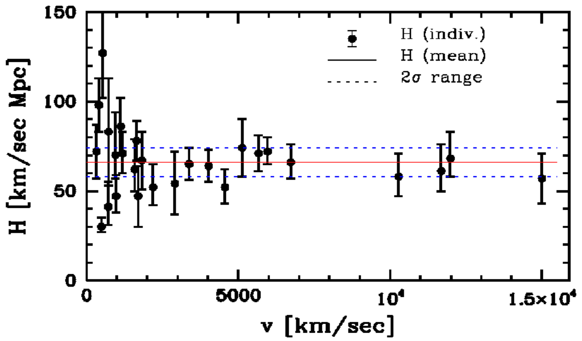
M"uller and Hoeflich 1994: 66 +- 6 (1 σ) km/sec/Mpc

Fisher et al 1995: 60 (1 σ) km/sec/Mpc

Riess et al. 1996: 67 +- 5 (1 σ) km/sec/Mpc

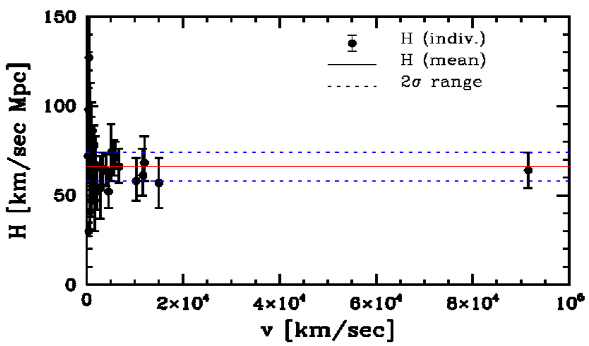
Hamuy et al. 1996: 63 +- 6 (1 σ) km/sec/Mpc

Nugent et al. 1996: 59 km/sec/Mpc



SNe~Ia with z < 0.05 (=230 Mpc)

67 +- 8 (2 σ) km/sec/Mpc



SNe~Ia with z < 0.38 (= 1.3 Gpc)

- SN88z (Nordgart et al. 1988)

- No evidence for local fluctuations

VI) Evolutionary Effects with Redshift (HTW98, ApJ 495, 617)

INFLUENCE OF THE C/O RATIO AND Z OF THE WD

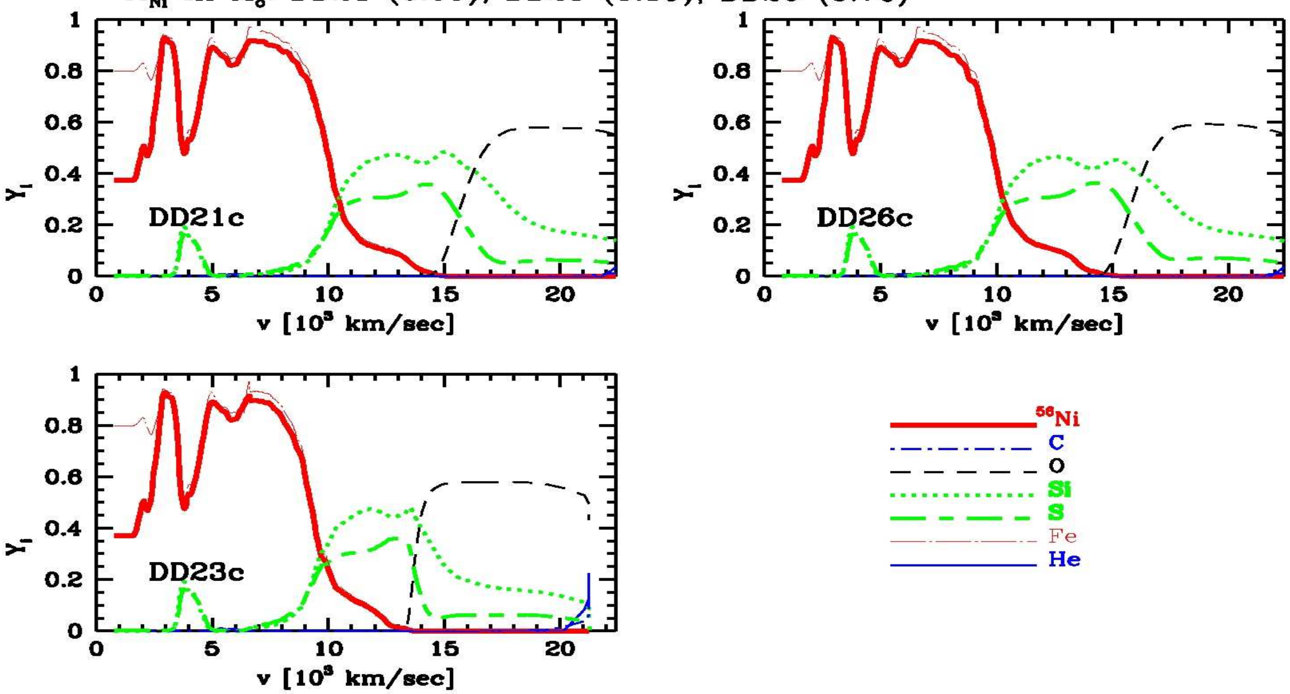
Example: DD, ρ_c = 2.6E9 c.g.s.; ρ_{tr} = 2.4E7 c.g.s.

DD21: C/O ratio = 1/1; Z = solar

DD23: C/O ratio = 2/3; Z = solar

DD24: C/O ratio = 1/1; Z = solar/3

- Si/S expands slower by 1000 km/s in DD23
- O expands slower 2000 km/s in DD23
- Metalicity has hardly any influence on dominant elements
- M_{Ni} in $M_\odot$: DD21 (0.69); DD23 (0.59); DD26 (0.70)



INFLUENCE of Z ON RARE ELEMENTS

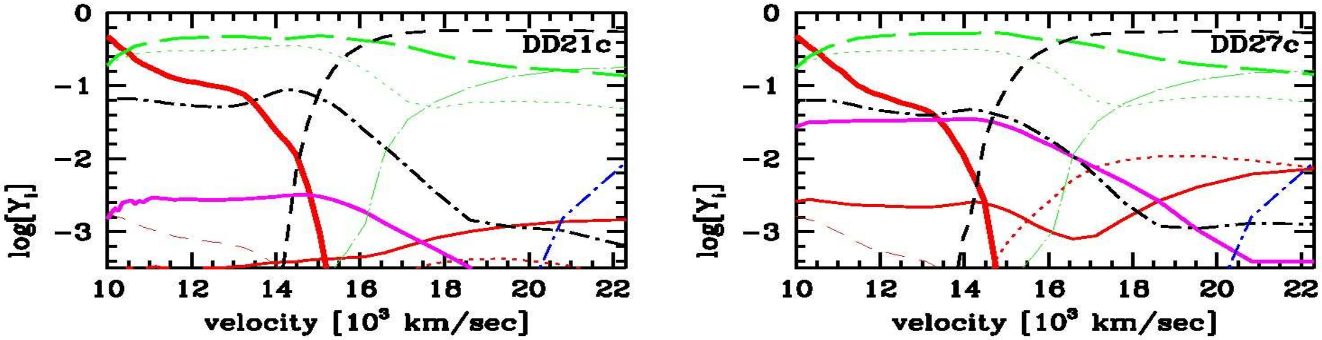
Example: DD, ρ_c = 2.6E9 c.g.s.; ρ_{tr} = 2.4E7 c.g.s.

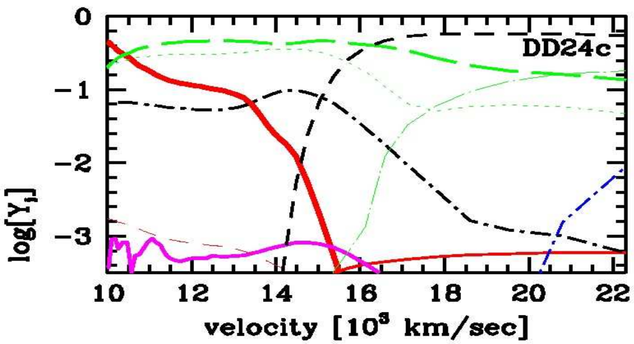
DD21: Z = solar
DD24: Z = solar/3
DD27: Z = 10*solar

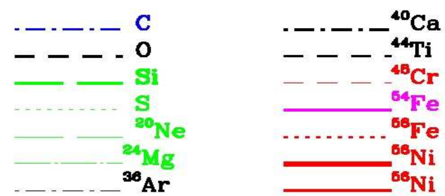
– ^{54}Fe production depends sensitively on Z

– ^{54}Fe is the dominant isotope at outer layers

– Nuclear burning changes Fe–group abundances







Ye=p/(p+n) comes from massive progenitors
14N(alpha,gam)18F(beta+)18O(alpha,gam)22Ne

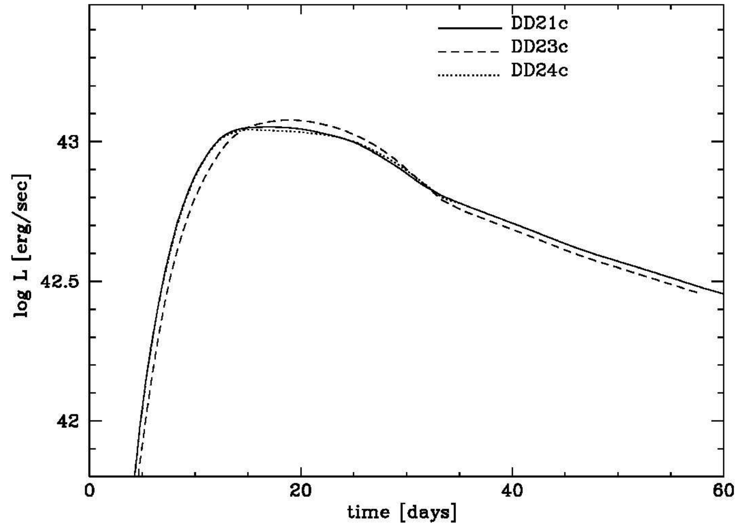
INFLUENCE ON LIGHT CURVES (0-60 Days)

DD21c: C/O=1/1; Z=0.02 (solar)

DD23c: C/O=2/3; Z=0.02 (solar)

DD24c: C/O=1/1; Z=0.0067 (solar/3)

Bolometric Light Curves



C/O Ratio of the WD

- Maxima ≈ 2-3 days later (i.g. 1-5 days)

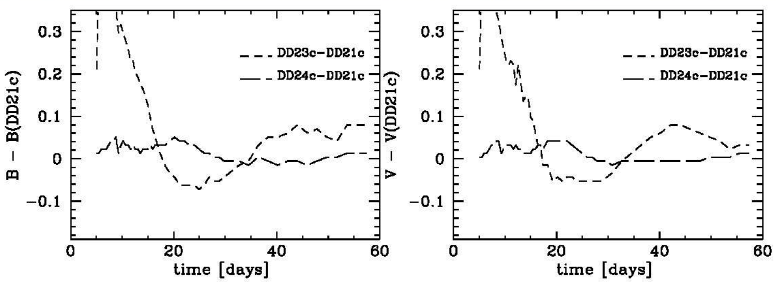
- Peak to 'Tail' ratio changes by $\approx 0.3^m$

Metalicity Z - negligible

OFF-SET in M(dM15)

dM(V) $\simeq$ 0.1 dt(rise)

Change of Monochromatic Light Curves rel. DD21c



INFLUENCE ON SPECTRA

DD21c: C/O=1/1; Z=0.02 (solar)

DD23c: C/O=2/3; Z=0.02 (solar)

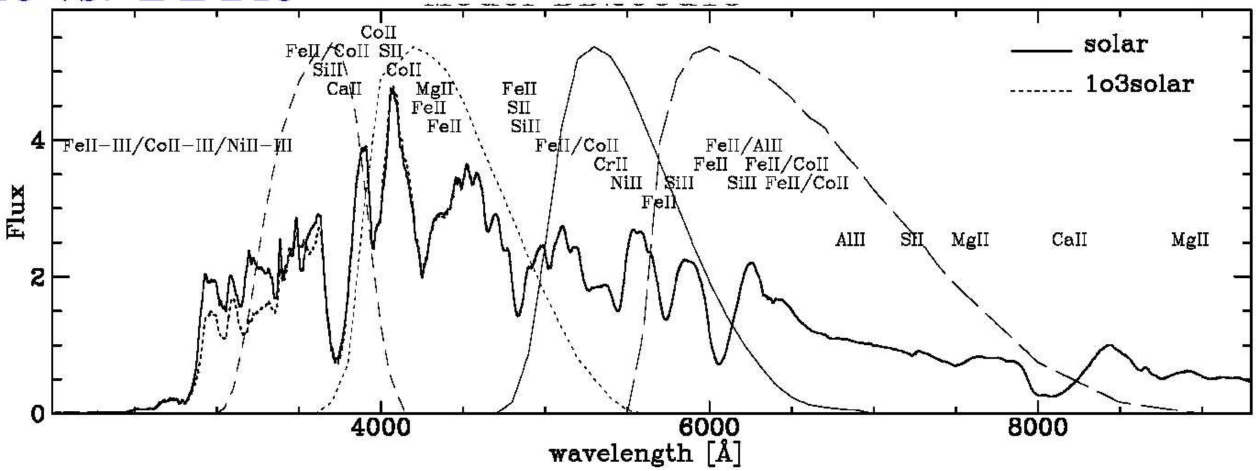
DD24c: C/O=1/1; Z=0.0067 (solar/3)

I) C/O ratio in the WD

- smaller Doppler shift in spectra ($\approx$ 700 km/sec)

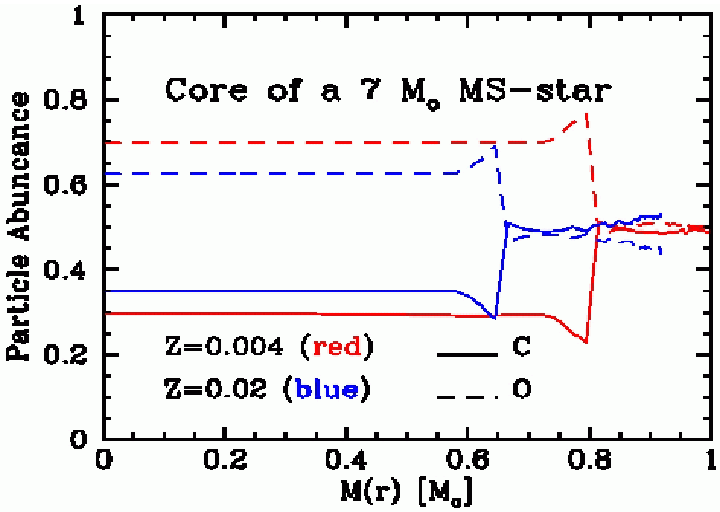
II) Metalicity Z

DD21c vs. DD24c



Progenitor Structures, Metallicity Dependence and Consequences for the Light Curves of SNeIa

(Hoeflich, Nomoto, Umeda & Wheeler 2000, ApJ 528, 854)



EXPLOSION MODELS:

Mass = 1.38 $M_\odot$

ρ_c = 2.5E9 g/ccm

ρ_{tr} = 2.7E7 g/ccm

α = 0.02 c_s

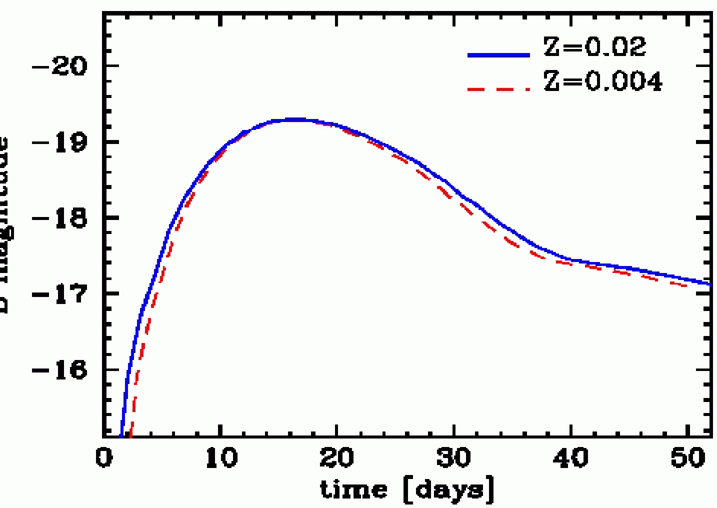
$(C/O)_{M(Ch)}$=0.38/0.43

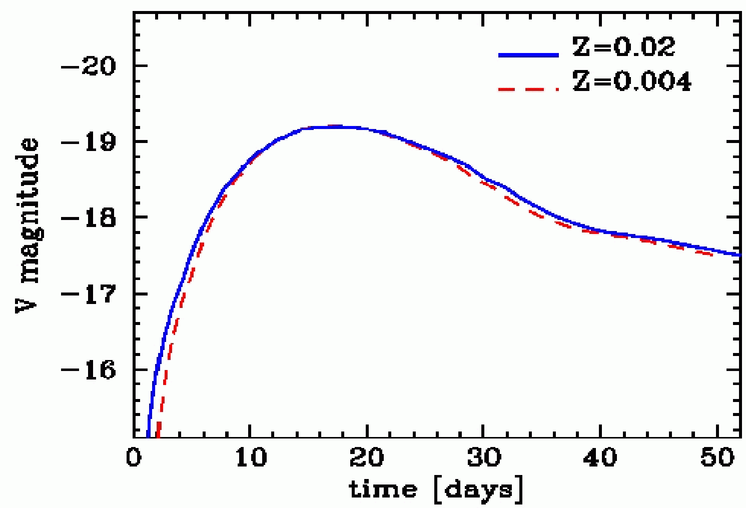
M_V (high−low Z) = 0.02^m

$M_V(dM_{15})$ = 0.1^m

dt_V (high−low Z)= −1d

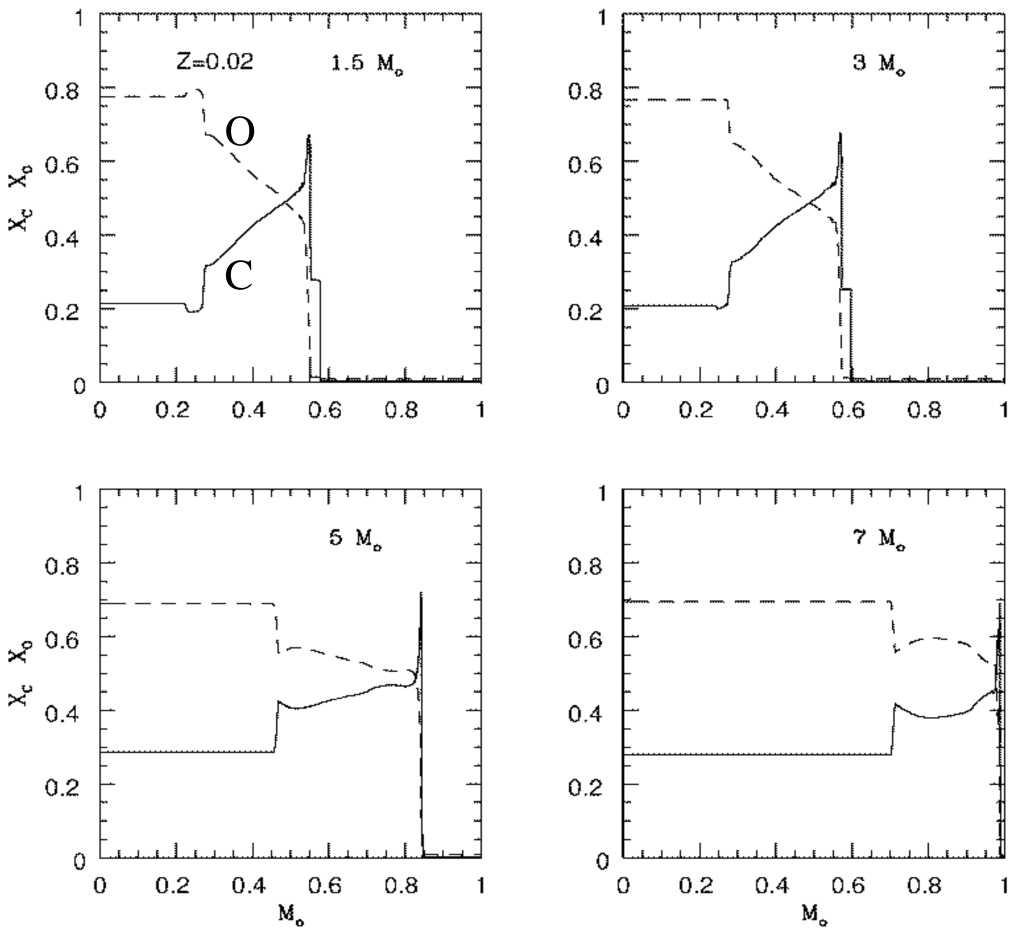
In general: $\Delta M \approx 0.1\ \Delta t$(rise)





Influence of the MS mass and Z

(Dominguez, Hoeflich, Straniero 2001, ApJ 557, 279)



- Size of C-depleted core depends on central He burning during the stellar evolution

=> f(MS)

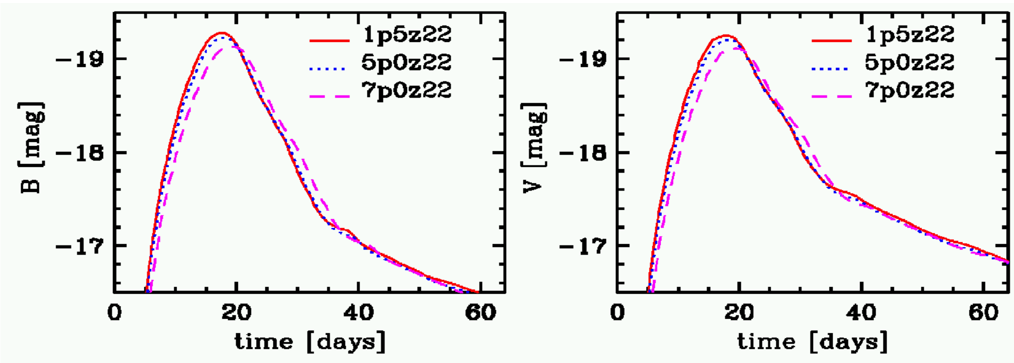
=> Explosion energy f(MS)

Influence of the Progenitor properties on the LCs

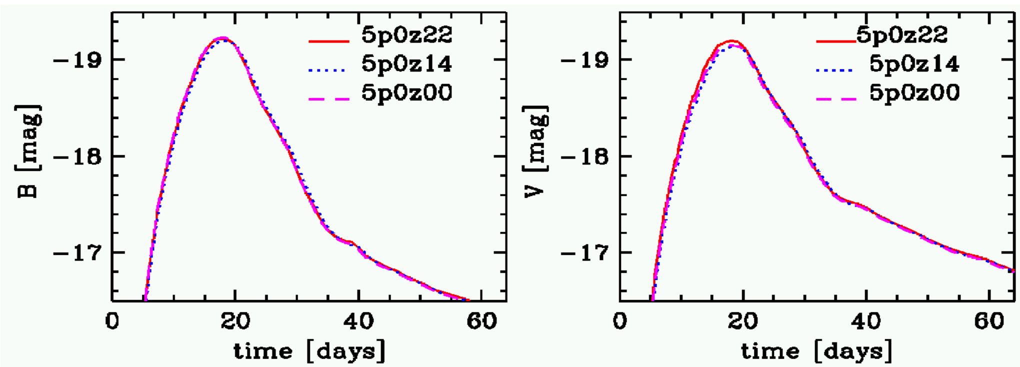
(Dominguez, Hoeflich & Straniero 2001, ApJ 557, 279)

Study of progenitors between 1.5 to 7 Mo and Z=0 to 0.02 (solar) and a DD-model

a) Influence of the mass on the main sequence



b) Influence of the matallicity Z

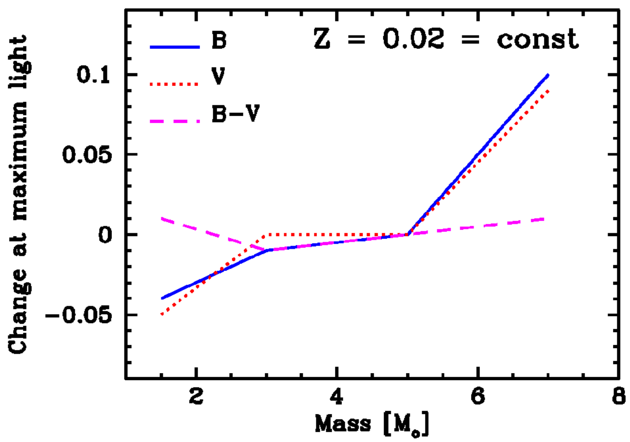


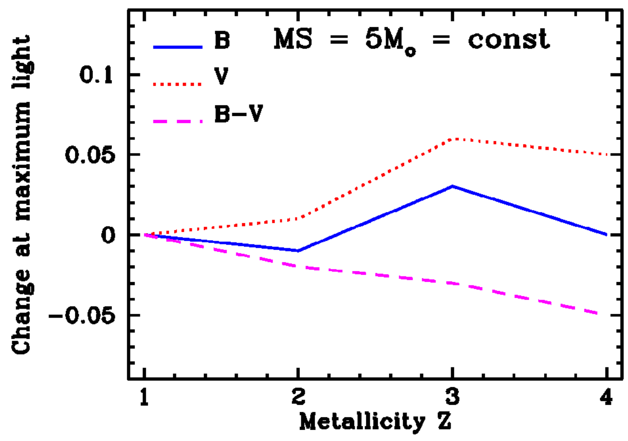
- **progenitor mass is the dominant effect**
- **maximum off-set in the brightness decline relation 0.2 mag**
- **ΔM(offset)= 0.1 t(rise)**
- **an off-set of 0.2 mag goes along with a reduced doppler shift of lines by 2000km/sec (Second parameter !!!)**

Change of properties at maximum light

Mass produced offset in Δ M(15)
=> critical for relation

Z changes B-V by 0.05mag-> A(V)=0.15m
=> critical for correction by interstellar dust





Current limits on evolutionary effects up to z of about 0.8:

Rise-time tV to MV:
(Riess et al. 1999 AJ 118, 2675)

$$t_V = \frac{19.4 \pm 0.2d + (0.80 \pm 0.05d)(M_V + 19.45^m)}{0.1^m} .$$

Spread in fiducial rise times (normalized to s=1) < 1 day
(Aldering et al. 2000, AJ 119, 2110)

===> (with model relation) offset in ΔM(15) of less than 0.1 mag up to z=1
and most progenitors should come from a more narrow range of masses (M>3 Mo)

Summay of evolutionary effects on LCs and spectra

Feature	Effect on LC & spectra	Order of effect
Initial metallicity Z	a) little effect on B, V, R, I, ...	
	b) strong influence on U and UV	factor 3 in Z -> 0.2 to 0.5m
	c) Strong, individual lines (e.g. 1mu FeII)	PopI -> strong line/ PopII-> no l.
C/O ration depends	a) Change of the rise-time/decline rel.	ΔM = 0.1 Δt[days])
on MS mass of prog.	b) Expansion velocities (Doppler shift of lines)	Δv(Si)[km/sec]= **+20,000 Δ** M
and Z	c) Peak/Tail ratio PT	PT = C Δ M with **C ≅ 1+**
Change of central density rho of the initial WD ->region with neutron capture increases	a) Similar brightness at maximum for same 56 Ni production but faster, earlier rise and slower decline with increasing rho	A change of rho(c) from 1.5E9 to 2.5E9 g/ccm changes width of LC by 2 days = 0.2 mag
	b) Peak to tail ratio changes	PT = C Δ M with **C ≅ -1**
	c) Si velocity at maximum light and asymtotic Si velocity is higher	Δ(Si)[km/sec] = **-20,000** ΔM
Merger/PDDs vs. classical DD	a) Slower rise and decline compared to DD	change by about 2 to 4 days
	b) Spectra: significant of C/O	C/O down to 13,-14000 km/sec upper limit of Mg, etc.

Final Discussion and Conclusions

Physics of Supernovae

- LC and flux and polarization spectra allow for a detailed analysis of SN.
  New IR observations + polarization are a key to probe the physics of the burning fronts.

- Most observations can be understood by "delayed detonation" models (or, maybe, very fast deflagration fronts). M(V)=dM(15d) is due to an opacity effect and governed by the transition density.

- Preconditioning of the WD prior to the explosion is a key to understand the differences.

Distance Indicators and Cosmology

- Individual distances of SNe Ia are 'good' to about 15-25 %.

- Ho = 67 +- 7 km/sec/Mpc

- Spectra and LC allow to detect evolutionary effects

- Observed relation between rise and decline of LCs suggest progenitors with M(MS)>3Mo

- Limits on the observed differences between local and distant SN are less than 0.1 mag ->
  not the end of this story => we need LAMBDA!

Future Perspectives, Problems & Wish-list

- New generation of telescopes (VLT, SNAP,SIRTF)

- How do we go into the thermonuclear runaway?

- surface burning on a WD (Seismology)

- nuclear burning in the non-linear regime

- more polarization measurements in SNeIa

- different scenarios end up as a SNeIa

- quest for the nature of the dark energy